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# PREDICTION OF EXCESS ATTENUATION SPECTRUM FOR NATURAL GROUND COVER

By

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## ABSTRACT

In earlier portions of the present research program, a precise mathematical model was developed for the estimation of sound absorption over a ground cover layer. The usefulness and validity of this analysis was confirmed by results obtained through a laboratory-scaled experiment. In the present study, the above mentioned mathematical model is applied to the prediction of sound absorption over various types of ground covers composed of natural vegetations. Through an extensive review of literature in agriculture and forestry, the physical structure and relevant mechanical properties of ground cover canopies have been determined. The acoustical properties of the ground cover itself has also been estimated. Based on these results, ground absorption spectra over various assumed ground cover conditions have been calculated. The trends of the prediction have been compared with experimental results and the limitations of the present study are discussed.

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## 1.0 INTRODUCTION

In earlier parts of the present study of sound absorption by natural ground cover, a mathematical model has been developed for estimating the sound absorption spectrum. The usefulness and validity of this model was confirmed by results from a laboratory-scaled experiment of sound attenuation by simulated ground cover (Reference 1). In this model the ground cover is represented as a layer of acoustical material of finite thickness. The concept is an extension of a representation chosen by Ingard (Reference 2), where the ground or ground cover is designated as a semi-infinite medium. The analysis is straightforward, and should be very accurate in the far-field.

The peak absorption frequency and the general shape of the sound absorption spectrum depend upon several principal parameters: the height of the sound source above the ground; the thickness of the ground cover; acoustical properties of the ground cover; and the normal acoustical impedance on the surface of the semi-infinite ground. In this report, a detailed study of the mechanical structures of natural ground cover such as forests and field crops, has been undertaken. According to their mechanical properties, the acoustical properties of natural ground cover are estimated. Thus, it is feasible to make realistic predictions of sound absorption spectra of natural ground covers over a considerable range of conditions. The results are presented in both graphical and tabulated forms. With increased knowledge of the acoustical properties of the ground cover, refinements of the predicted values can be made in the future. However, the present results are considered to be suitable for preliminary estimates of ground absorption of sound in field conditions.

In the remainder of this report, a condensed description of the analysis and the resulting equations are given in Section 2.0; a general description of the structure of different types of forest and field crops is presented in Section 3.0; the detailed estimation of acoustical properties of natural ground covers is discussed in Section 4.0; the predictions of ground absorption spectra under a range of given conditions are presented in Section 5.0; and finally, the limitations of the present study and other general discussions are included in Section 6.0. In addition, a FORTRAN computer program which performs the calculation of the sound absorption spectrum is documented and listed in the Appendix.

## 2.0 MATHEMATICAL ANALYSIS

The precise analytic nature of sound attenuation near a boundary with known acoustic impedance was first made clear in a series of studies by Rudnick (Reference 3), and Ingard (Reference 2). The main application has been the estimation of ground attenuation effects on sound propagation in the atmosphere. Some subsequent analytical studies and experiments have further explored the details of this phenomenon. In these studies, the acoustic media above and below the boundary plane are assumed to be semi-infinite. Constant values are ascribed to either the impedances of the two media or the normal impedance of the boundary itself. However, in many situations with practical importance, the boundary between the upper and the lower semi-infinite acoustic media is not a simple plane, but a porous layer with finite thickness. It is natural, then, to investigate the wave attenuation characteristics near such a composite boundary.

Owing to the special nature of wave reflections at near glancing angles of incidence, it is not possible to assign a constant value of impedance to the entire composite boundary. A layered media representation becomes necessary in this case. It is necessary to specify both the acoustic impedance and the wave transmission constant of the porous transition layer. A new analysis is therefore required for estimating the magnitude and characteristics of the ground attenuation of such a layered boundary.

In addition to the analysis, an experimental study was undertaken in the previous year (Reference 1) to determine the attenuation characteristics of a layered boundary. The results of the experiment were intended for the verification of the theory as well as for obtaining a separate view of the problem from an independent approach. The experiment was performed under laboratory conditions so that the ground attenuation effects were studied without the uncertainty of other complications, such as wind refraction and turbulent scattering. Overall, the study found significant departure in several aspects of the attenuation characteristics of a layered media from those of a simple boundary. Thus, one may find the results useful in dealing with a variety of practical problems where a layered representation of the boundaries is warranted.

Geometrically, the space is assumed to be divided into three layers. The top semi-infinite layer is assumed to be air, which has a density of $\rho_0$, speed of sound $c_0$, and acoustic impedance of $\rho_0 c_0$. The middle layer is assumed to be a porous material. Its density and speed of sound are, in general, complex quantities. In other words, it has a complex acoustic impedance such that a plane wave transmitted from the air into this layer will be refracted into the layer with a phase shift, and will be attenuated as it propagates through this material. A third medium, which represents the ground, occupies the lower half-space. To simplify the analysis, a constant normal impedance is prescribed at the interface between the middle layer and the semi-infinite ground.

As pointed out in previous studies, the simple ray acoustics approach cannot account for the observed ground attenuation phonomenon, and a more rigorous mathematical analysis must be followed. In the present study, the approach of Ingard (Reference 2), together with coordinate systems and symbols in that paper, is adapted.

A spherical wavefront which originates from a point source can be represented as an integral of its plane-wave elements

$$\frac{e^{ikr}}{kr} = \left(\frac{i}{2\pi}\right) \int_0^{2\pi} d\phi \int_0^{\pi/2+i\infty} e^{i[k_1 x+k_2 y+k_3(h-z)]} \sin\theta \, d\theta \qquad (1)$$

In the above integral, the vector $(k_1, k_2, k_3)$ indentifies the wavenumber of a plane-wave element, and h denotes the height of the sound source above the top of the layered boundary. The reflection of the primary wave at a boundary can then be represented as

$$p_r = \left(\frac{i}{2\pi}\right) \int_0^{2\pi} d\phi \int_0^{\pi/2+i\infty} e^{i[k_1 x+k_2 y+k_3(h+z)]} R(\phi,\theta) \sin\theta \, d\theta \qquad (2)$$

where $R(\phi,\theta)$ is the plane-wave reflection coefficient. The reflection coefficient $R(\phi,\theta)$ is a function of $\phi$ and $\theta$.

It is more convenient for the purpose of integration to write Equation (2) in a new spherical coordinate system where the principal direction of the reflected ray is chosen as the reference axis (Reference 2). The new angular variables are defined as $\psi$ and $\eta$. Equation (2) can now be represented as

$$p_r = \left(\frac{i}{2\pi}\right) \int_0^{2\pi} d\psi \int_0^{\pi/2+i\infty} e^{ikr_2\cos\eta} R(\psi,\eta) \sin\eta \, d\eta \qquad (3)$$

An integral of this form can be evaluated by using the method of steepest descent (Reference 9) in the acoustic farfield, where the value of $kr_2$ is large compared to unity. Along the paths of steepest descent in the complex $\eta$ plane, a new variable can be defined such that

$$\cos\eta = 1 + it \qquad (4)$$

where $t$ is real and positive. The reflected wave can be then written as

$$p_r = \frac{e^{ikr_2}}{kr_2}\left(kr_2\right)\int_0^{2\pi}\int_0^{\infty} e^{-kr_2 t}\, R(\psi, t)\, dt\, d\psi = \frac{e^{ikr_2}}{kr_2}\, Q \tag{5}$$

which has the form of a wave originating from an "image source" located at a distance $h$ below the top of the layered boundary, with a variable strength $Q$.

For an arbitrarily given function of $R(\psi,\theta)$, Equation (5) can only be integrated approximately. A first asymptotic approximation can be given as

$$p_r = \frac{e^{ikr_2}}{kr_2}\left\{ R(\gamma_0) + \frac{1}{ikr_2}\left[\frac{1}{2}(1-\gamma_0^2)\, R''(\gamma_0) - \gamma_0\, R'(\gamma_0)\right]\right\} \tag{6}$$

where

$$\gamma_0 = \cos\theta_0$$

$R'$ and $R''$ are the first and second derivates of $R$ with respect to $\gamma = \cos\theta$. Equation (6) serves as a starting point for the present analytical investigation into ground attenuation due to layered media.

It remains here to determine the plane-wave refraction coefficient $R(\theta)$ for a boundary with a layered configuration. The over-all reflection coefficient accounts for the wave reflection at the top of the middle layer, as well as the wave that is transmitted into the middle layer, relfected by the ground, and returned into the air. Hence, the over-all reflection coefficient of the layered boundary can be given as

$$R(\theta) = \frac{(\cos\theta - \beta_1 \cos\theta_1)}{(\cos\theta + \beta_1\cos\theta_1)} + \frac{4\beta_1 \cos\theta\cos\theta_1\,(\cos\theta_1 - \beta_2)\,\phi}{(\cos\theta + \beta_1\cos\theta_1)^2\,(\cos\theta_1 + \beta_2)} \tag{7}$$

with

$$\phi = \exp\left[2ih\,(n^2 - 1 + \cos^2\theta)^{1/2}\right]$$

$$\cos\theta_1 = n^{-1}\left[n^2 - 1 + \cos^2\theta\right]^{1/2}$$

where $\beta_1$ is the specific admittance ratio of the middle layer with respect to air, $\beta_2$ is the specific admittance ratio at the interface of the middle layer and the ground, and $\theta_1$ is the refraction angle in the middle layer. The function $\Phi$ accounts for the phase difference between the two reflected wave components. This phase shift is caused by path difference and the wave transmission characteristics of the middle layer.

The insrantaneous value of sound pressure in the farfield can now be determined as

$$p = \frac{e^{ikr_1}}{kr_1} \left( 1 + \frac{r_1}{r_2} e^{ik(r_2 - r_1)} \left\{ R(\gamma_0) + \frac{1}{ikr_2} \times \right. \right.$$

$$\left. \left. \times \left[ \frac{1}{2} (1-\gamma_0^2) R''(\gamma_0) - \gamma_0 R'(\gamma_0) \right] \right\} \right) \qquad (8)$$

The derivatives of $R(\theta)$ with respect to $\cos\theta$ can be obtained from Equation (7). By substituting the known expressions for $R(\theta)$, $R'$, and $R''$ into Equation (6), an explicit expression can be obtained for the reflected wave. The attenuation of sound near the layered boundary can now be obtained by simply adding the incident and the reflected sound-pressure fields.

The algebraic expressions involved in computing the sound-pressure field in the upper half space are straightforward but relatively bulky. Therefore, the results have been programmed for computer calculation. The asymptotic approximate solution is very accurate for computing sound-pressure levels in the farfield, i.e., points that are more than a few wavelengths away from the sound source. For the study of ground attenuation effects, this is an insignificant restriction. In the computing program, all of the geometrical and acoustical parameters can be varied independently. In particular, the specific admittance ratios $\beta_1$, $\beta_2$ and the refraction index n are assumed to be complex numbers.

# 3.0 THE STRUCTURE OF FORESTS AND FIELDS

The structure of natural ground cover is determined by a wide variety of factors. Climate, terrain, soil condition, rainfall, plant species, and the plant community regeneration process all come into effect. For the present study, it is important to know the values of parameters such as height, foliage density in the canopy, stratification of the canopy, nature of the undergrowth, and seasonal variations. Many of these properties have been studied extensively in forestry literature. However, since each forest being studied has its own special features, descriptions are very difficult to make (References 4 through 10).

In this section, the general appearance and common variation of ecological conditions of three major categories of ground cover vegetations will be discussed. These main categories are:

- The temperate forest
- The tropical rain forest
- The grain crop and the grass fields

The outward appearance and the fine structure of ground cover are entirely different for each of these broad categories. Further classification with each category will be defined in the course of the discussions.

## 3.1 The Temperate Forest

In the temperate forest, the plant community is commonly dominated by individual trees from only a few species. A single temperate forest rarely contains more than twenty species of plant life forms. Most of the time, the ranking of the plant species and their roles in the forest are clearly recognizable. The trees in a temperate forest can be classified into five groups: standard trees; dominant trees; codominant trees; dominated trees; and suppressed trees. Their descriptions are given below.

Standard Trees: These are isolated large trees in the stand. Their trunk diameters are significantly larger than average and the crowns are fully developed.

Dominant Trees: As a rule, these trees form the main part of the stand, and have relatively well developed crowns.

Codominant Trees: These trees have fairly normal, but comparatively weak and narrow developed crowns.

Dominated Trees: The crowns are more or less stunted with one side developed, or suffer severe pressure on one or more sides.

(a) Trees with crowns in the middle story, their heads mainly free but in most cases completely surrounded.

(b) Trees with crowns partly in the undergrowth.

Suppressed Trees: These trees are

(a) Trees with crowns capable of survival.

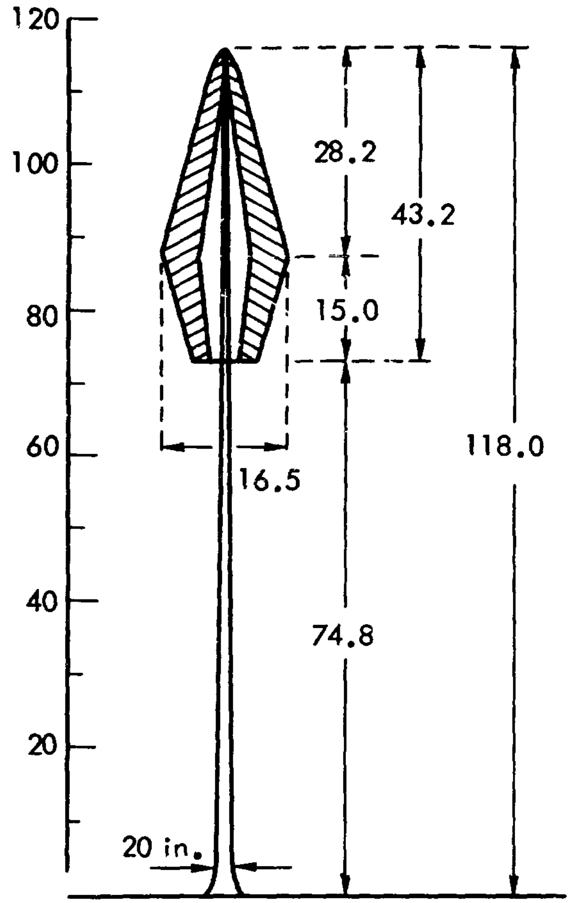
(b) Trees with crowns dying or completely dead.

The main foliage canopy is formed by the crowns of the standard trees, dominant trees, and the codiminant trees. Trees in these three classes have approximately the same height; their differences are mainly their sizes and the crown development. The bottom of the canopy is clearly defined in most cases. Undergrowth in a temperate forest is usually sparse and orderly, and is composed of mainly seedling trees, sapling trees, other small trees, and shrubs. The height of small trees and shrubs is somewhat lower than the bottom of the main canopy. In most of the temperate forest, there is only one main canopy. Only on rare occasions are there two stories of canopy.

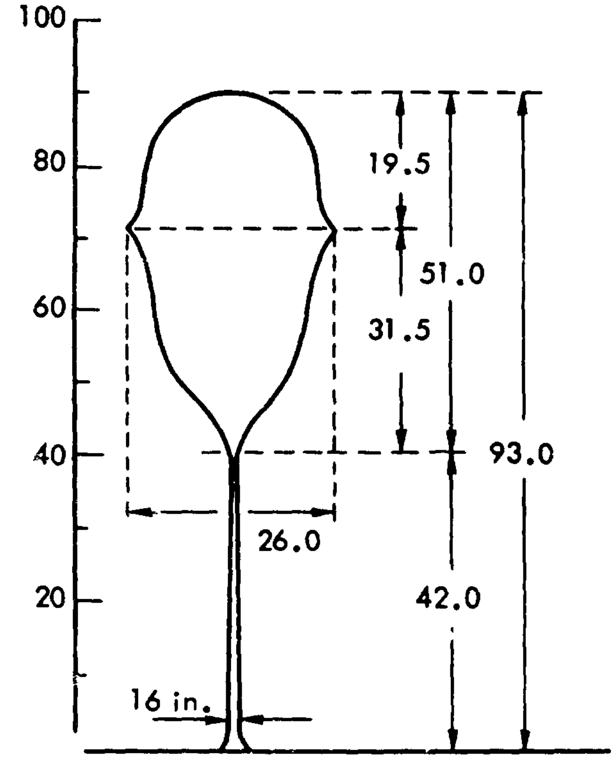
On the floor of the forest, there is commonly a shallow layer of fallen leaves and twigs, together with some growth of herbaceous plants. Otherwise, there should be no major obstacles to interfere with clear passage on foot. Visibility through the tree stands is variable, depending mainly on the height of the lowest level of branches on a tree, and the seasonal manifestation of foliage and floration in the forest trees and the undergrowth.

There are two main types of forests in the temperate zone: deciduous and evergreen. Most of the deciduous trees are broad-leaf trees. However, a few species of needle-leaf trees, such as eastern larch, are also deciduous. In a deciduous forest, seasonal variation of foliage color and density can provide very striking changes of the appearance of the forest stand. A mature deciduous forest reaches a height of approximately 80 ft. The bottom of the main canopy is 30 to 40 feet above the ground, and the closed canopy is about 30 to 50 feet in thickness. A typical deciduous tree model is shown in Figure 1(b). Owing to the variation of weather and water supply, the foliage density in the main canopy can change not only with the season, but also from year to year.

The dominant species for forest stands in the same general geographical region can be different from location to location. The overall pattern may appear to be a mosaic of splendid proportion. It is interesting to note that the seedlings and saplings in a temperate forest stand may not belong to the same species as the dominant or codominant trees in the same stand. This is because the saplings of the dominant species may not be able to survive the shade under the forest canopy. Hence, young trees of a persistent and shade tolerant species will flourish, and eventually take over as the dominant species in the next succession. Such a sequence of change in the dominant




a) Crown Model of a 98-year-old Spruce from a Closed Stand




b) Crown Model of a Dominant 88-year-old Beech

Figure 1. Model Trees in Temperate Forests. All dimensions are in feet. (Reference 8)

species has long been observed. For example, red maple will succeed blackgum, and be replaced by beech (Reference 9).

In a temperate evergreen forest, the dominant species are needle-leaf trees. These species are generally called conifers. A mature evergreen forest can reach a height of at least 120 feet. The thickness of the closed canopy is about 40 to 50 feet, the same as the deciduous forest. Thus, the bottom of the canopy can be as high as 70 to 80 feet above the ground. Typical tree models are shown in Figure 1(a) and Figure 2. A conifer can keep its leaves for three to eight years. Both new and old leaves are therefore staying simultaneously on the branches. As a consequence, the evergreen tree has a much greater leaf mass than a deciduous tree of the same size. Since the evergreen forest has a much greater leaf-area, and the leaves are functioning most of the year for the assimulation of bio-mass, it has a greater growth rate than a deciduous forest. For this reason, management of evergreen forest crops for timber has long been in practice. Such managed forests are widespread geographically.

In a managed forest, the tree stands can either be even-aged, or graded in age and size by means of rotation and selection. Such forests can achieve their optimum density of foliage for maximum forest yield. It is important to note that in a young even-aged conifer stand the trees have almost as much foliage as a mature conifer stand. In comparison with a mature forest, a young tree stand has a higher number density, a larger crown height to width ratio, and a larger number of leaves per branch. In fact, leaves and small limbs of a young conifer stand may account for 50% to 60% of the total plant mass above the ground.

Other than the major types of forest as discussed above, there are also shrubs and orchards which may cover large areas of land. In general, the temperate forests, including small trees and shrubs, have a homogeneous and relatively simple structure. The main canopy is commonly uniform in thickness, and has clearly defined top and bottom. Undergrowth density is sparse, and its height is moderately below the bottom of the main canopy. Density of the canopy depends on the species and seasons. From a well stocked evergreen forest to a deciduous forest in winter, the foliage density varies greatly. Correspondingly, their effects on ground attenuation of sound can also be significantly different.

### 3.2 The Tropical Rain Forest

In a tropical rain forest, the plant community is extremely complicated. Some times, it seems to be such a chaos that nature appears to be anxious to fill every available space with stems and leaves. Nevertheless, order prevails in the rain forests upon close studies of the arrangement of the forest canopy and the ecology of the plant community. Unlike the temperate forest, one seldom finds less than forty species of plant life in any particular tropical rain forest locality. Most of the plants are woody, and have thick leathery leaves. This may very well be the result of physical adaptation to the humidity, temperature, and the strength required to withstand heavy downpours in the tropical zone.

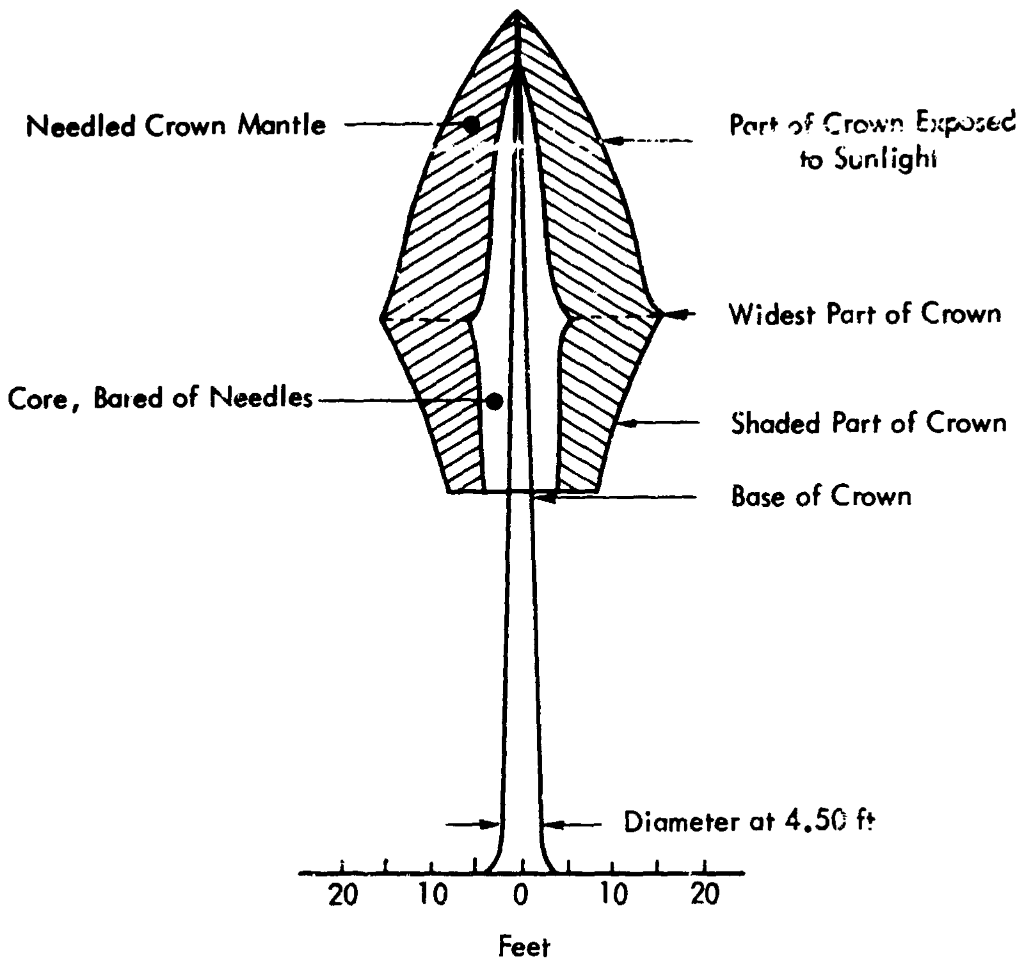



Figure 2. Model of a Spruce Crown (Reference 8)

Most of the tropical rain forests are evergreen in appearance. However, there are also deciduous tree species in a tropical rain forest. A single tree, or a group of trees may suddenly change color in their foliage, and lose all the leaves for a short period of time, say, from a few days to a few weeks. The leaf renewal cycle is not necessarily annual. It can lie between eight months to two and a half years, and is not uniform even for trees of the same species. Also, renewal and shedding of leaves are not strongly related to the dry seasons in the tropical zone. Normally, all the deciduous species are large trees. Nearly all the undergrowth plants are evergreen.

In a tropical rain forest, the crowns of the trees are arranged in many stories. Although no standard of classification has been agreed upon in the literature, some general description is possible. According to Richards (Reference 7), most of the mixed tropical forest stands have a so-called A, B, C structure. The A-story is composed mainly of standard trees. These trees are very large, and their crowns develop freely. However, the crowns in this story seldom form a closed canopy. The B-story is composed of dominant and codominant trees. A thick and nearly closed canopy is formed. There are also the smaller trees, not necessarily of the same species as the dominant or codominant trees, which will form a lower canopy, and is called the C-story. A typical configuration is given in Figure 3.

Other than the mixed forest, there are also some tropical rain forests which are dominated by a single species of large trees. The single-dominant forests have a somewhat different structure. Instead of the A, B, C-structure as described above, such forests can be said to have an A,C-structure.

The condition of undergrowth inside a tropical rain forest is much more open than the cluttered and impenetrable appearance as described in many literary writing. There are two possible reasons that such impressions were conceived by earlier writers and travellers. It is possible that most of the early travellers made their passage through the tropical rain forests on waterways and trails. Both light and water are richly available along the banks of streams and rivers. Hence the undergrowth can expand to an impressive thickness at all heights under the tree canopies. Similar conditions prevail along trails where sunlight is readily available. Another reason, as offered by Richards, is that the exaggerated manifestation of tropical plant forms would tempt the early explorers to write accordingly. In general, the undergrowth in tropical rain forests is much denser than those in a temperate forest. It contains also a much larger variety of species of plant. However, passage on foot through the jungle floor is not too difficult, though it may be necessary sometimes to remove a low-hanging branch. Visibility inside the tropical rain forest is generally fair. It depends mainly on the density of foliages at eye level. Hence, visibility is not an accurate indicator of the density of plant masses in the forest as a whole. These comments can be applied equally well to visibility conditions in a temperate forest.


Figure 3. Profile Diagram of Primary Mixed Dipterocarp Forest, Mt Dulit, Borneo. The diagram represents a strip of forest 200 ft long and 25 ft wide. Only trees over 25 ft high are shown. (After Richards, Reference 7.)

A special feature in tropical rain forests is the abundance in growth of woody lianas. These climbing species can reach great heights and their stems can have diameters of up to a few inches. Their interaction with the tree species in the tropical rain forest can become an important part of the overall plant ecology in certain locations. The abundance of dependent and semi-dependent species is also characteristic of the rain forests. The presence of these plants often adds significantly to the dramatic appearance of a tropical rain forest.

In general, tropical rain forests include not only the "wet" evergreen forests as described above, but also some other forms of forests under limiting conditions. In parts of the tropical zone, rainfall and mineral resources in the soil can fall far below their normal conditions. Depending on the severity of these limitations, a typical tropical rain forest can degenerate into a seasonal evergreen forest, a seasonal semi-evergreen forest, a deciduous forest, shrubs and small trees, or simply a field of thorn and cactus. A figure showing the general configuration and plant density in these forms of tropical forests is adapted from Reference 7 (Figure 4).

## 3.3 The Grain Crop and the Grass Fields

Grain fields and pastures are perhaps the most expansive types of ground cover. Inspite of the large variety in grain and grass species, their structural appearances are generally similar. The entire canopy is commonly composed of purely a single species, perhaps at most two to three; it is homogeneous; and it has a uniform canopy thickness. Most of the field crops are annual plant species: woody growth is uncommon except special cases such as cotton and alfalfa. Leaves form the major portion of the plant mass in the canopy.

The height and density of the canopy depend mainly on the species and the practice of cultivation. Tall species include corn, wheat, barley, and sugar cane; medium height species include rice, alfalfa, and timothy; short species include many common grasses such as clover and bluegrass. Canopies with the highest densities are sugar cane and corn for the tall species, and rice and clover for the short species. Actually, the density in the canopy depends greatly on the stage of growth and the moisture content at a particular time. The detailed quantitative description of the structure of field crops will be discussed in the next section.


Figure 4. Profile Diagrams of Climatic Plant Formations in Lowlands of Trinidad, British West Indies, and Neighboring Part of Venezuela (Reference 7).

## 4.0 THE ACOUSTIC PROPERTIES OF GROUND COVER

Materials commonly used in noise reduction or noise control engineering are mostly porous acoustical materials. Basically, such materials are composed of either a fiber matrix where air may pass through the remaining empty space, or simply a homogeneous solid with numerous open and close ended air passages embedded in it. When sound is propagating in such a medium, the air in the void is assumed to be the main wave carrier. At the passage of sound wave, the friction between the moving air particle and the surface of the solid matrix will cause a loss of acoustic energy. Moreover, the elastic properties of wave propagation in small air passages can be significantly different from the corresponding properties in free air. In many porous acoustical materials, heat transfer occurs between the air and the solid. The bulk elasticity coefficient of air will take its value under isothermal conditions, instead of its usual value under adiabatic conditions for sound propagation in free air. The solid matrix may, or may not, respond to the sound pressure fluctuation. For some porous material, the matrix has a rigid structure, and thus remains stationary for wave passage at all frequencies. For others, the structure of the matrix is relatively compliant. At low frequencies, the solid matrix oscillates with the surrounding air. Each of these types of porous acoustical material has different acoustical properties.

In Reference 11, Beranek introduced a method to estimate the acoustical properties of porous materials. The structural properties of a typical porous acoustical material can be represented by the following parameters:

| | | |
|---|---|---|
| $\rho_m$ | = | density of acoustical material |
| $Y$ | = | porosity, the ratio of volume of voids in material to total volume |
| $k$ | = | structure factor, an empirical constant to indicate the nature interstices in skeleton |
| $R_1$ | = | alternating flow resistance for unit thickness of material |
| $Q$ | = | volume coefficient of elasticity of acoustical material |
| $\rho_0$ | = | density of air |
| $K$ | = | volume coefficient of elasticity of air for isothermal conditions. |

In Reference 11, all units are defined in mks units. The unit for alternating flow resistance is defined as mks rayls. Two types of acoustical materials are considered by Beranek: materials with a rigid matrix; and, materials with a soft matrix where $K > 20Q$. Important acoustical parameters are defined:

$b$ = $(b_R + j\, b_I)$ = wave propagation constant

$Z_m$ = characteristic impedance of acoustical material

$C_m$ = speed of sound in the material

$\alpha$ = proportional to the real part of the wave propagation constant; it represents the attenuation coefficient of sound in the material per unit distance

$\omega = 2\pi f$ = frequency; radian/sec

$n$ = refraction coefficient

$\beta_1$ = specific admittance ratio with respect to air

$c_0$ = speed of sound in air

$Z_0$ = characteristic impedance of air

The wave propagation constant is defined such that the sound pressure fluctuation can be represented as a function of distance:

$$p(x) = \exp(-bx)$$

Generally, the sound wave propagates in the porous material at a speed lower than the speed of sound in air, and it attenuates as an exponential function of disrance or time. For materials with a rigid matrix, the following equations are given:

$$b = j\omega \left( \frac{\rho_0 \, k Y}{K} \right)^{1/2} \left( 1 - j \frac{R_1}{\rho_0 \, k \omega} \right)^{1/2} \tag{9}$$

and

$$Z_m = -j \frac{b K}{Y \omega} \tag{10}$$

For materials with a soft matrix, where $K > 20Q$, the equation for the wave propagation constant is:

$$b = j\omega \left( \frac{Y}{K} \right)^{1/2} \left\{ \langle \rho_1 \rangle - j \frac{\langle R \rangle}{\omega} \right\}^{1/2} \tag{11}$$

where

$$\langle R_1 \rangle = \frac{R_1 \left\{ 1 - \rho_0 \, (1-Y)/\rho_m \right\}}{\left\{ 1 + \rho_0 \, (k-1)/\rho_m \right\}^2 \left\{ 1 + (R/\rho_m \omega)^2 \left\{ 1 + \rho_0 \, (k-1)/\rho_m \right\}^{-2} \right\}} \tag{12}$$

and

$$\langle \rho_1 \rangle = \rho_0 k \, \frac{1 + \left( R_1/\rho_m \omega \right)^2 \left( Y + \rho_m/\rho_0 k \right) \left\{ 1 + \rho_0 \, (k-1)/\rho_m \right\}^{-2}}{1 + \left( R_1/\rho_m \omega \right)^2 \left\{ 1 + \rho_0 \, (k-1)/\rho_m \right\}^{-2}} \tag{13}$$

The quantities $\langle \rho_1 \rangle$ and $\langle R_1 \rangle$ are called the effective density and the effective flow resistance, respectively. Other acoustical parameters can be derived from the values of b and $Z_m$ :

$$c_m = \omega/b_I \; ; \quad n = c_0/c_m \; ; \; \beta_1 = Z_0/Z_m \tag{14}$$

Beranek had used these formulas to predict the acoustical parameters of a number of commercial acoustical porous material. The results agreed reasonably well with experimental measurements.

The structure of a forest canopy is typical of a porous acoustical material. The solid matrix is represented by stems, branches, and the foliage of the plants. The total area of exposed surface area of leaves and stems is appreciable, and a significant value of alternating flow resistance is expected.

The acoustical properties of ground cover can be estimated by using the Beranek equations. It is necessary, however, first to establish the structural parameters such as porosity, effective matrix density, and flow resistance. The evaluations of these parameters are discussed separately as given below.

## 4.1 Porosity

In a natural forest stand, the growth of the plants in the community is governed by the availability of light, mineral, water, and by their interdependence and the process of selection. The maximum amount of plant masses which can survive over a unit area of land is limited by these factors. In a well stocked forest stand, the average distance between two neighboring trees is approximately 12.5 times the average tree diameter at breast height (d.b.h., breast height is defined as 4.5 feet or 1.3 meters above the

ground). Most of the solid volume under the canopy is occupied by the trunks and branches. The rest of the solid material will be leaves, twigs, lianas, and undergrowth. The ratio between branchwood volume and stemwood volume is about one to four, depending on the condition of the individual forests. Hence, if the tree trunk is assumed to be conical in shape, it is easy to calculate that approximately 0.3 percent of the available space under the canopy is occupied by solid materials. According to accurate measurements of timber volume in various forest stands, the solid to total volume ratio can be as high as 0.45 to 0.52 percent.

On the other hand, some mixed deciduous forest stands, such as the oak-chestnut forest in the southeast United States, the average tree distance to diameter ratio can be as large as 20. In such cases, the solid volume to total volume ratio can be as low as 0.1%. In Table 1, some typical statistics for forest stands of various species is presented. In a forest, the total quantity of solid material represents the accumulated yield from biological activities over a period of many years. For the canopies of grain crops and pastures, the conditions are different. The total fresh weight of the plants is commonly between 5 to 15 ton/acre, depending on the canopy height and plant density. Hence, the solid volume to total volume ratio is limited to below approximately 0.3% . In many cases, this ratio can be as low as 0.05 to 0.1%. Hence, the porosity of a natural ground cover can have a value somewhere between 0.995 and 0.999.

## 4.2 Effective Density

From Equations (9) to (13), it can be seen that the density of the matrix material is meaningful only if such masses can respond to the sound pressure fluctuations in the air. It has been established in a study by Embleton (Reference 12) that even very small branches respond only slightly to sound. Hence, it is reasonable to assume that only the foliage in the canopy will respond to sound pressure fluctuation at very low frequencies, following the definition of Q in the Beranek model of porous acoustical material. In the literature, leaf mass has been measured in various experimental studies in forestry (References 5 through 10).

It is important to note that the strategy of leaf growth on any plant is governed perhaps entirely by the availability of sunlight. The photosynthesis process is fully effective only if the available light intensity is above 20% of the average sunlight intensity. In permanent shades where the light intensity falls much below this value, plant growth will be impossible except for a few species of plant with extremely high shade tolerance. It is explained by Horn (Reference 9) that there can be two strategies for leaf arrangement for plant growth over a fixed unit area of land: the multilayer strategy and the monolayer strategy. For an object in the sunlight, a shadow will be casted behind it. However, the "hard" shadow will disappear after 30 or 40 diameters away, because the sun is a light source of extremely large dimension. If a tree has adopted the multilayer strategy, then the leaves on the top layer will have an area density much less than the ground surface area, say, 50%. About 40 to 50 average leave diameters away, a second layer of leaves will be grown. Since the sunlight

TABLE 1

DENSITY OF VARIOUS TREE SPECIES FOR AVERAGE SITES
AT AGES OF CULMINATION

| Species | Average d.b.h., inch | Trees Per Acre | Basal Area Per Acre, sq ft | Average Separation Distance to d.b.h. * Ratio |
|---|---|---|---|---|
| Red Fir | 14.3 | 360 | 437 | 8.9 |
| Redwood | 10.4 | 628 | 372 | 9.6 |
| Red Gum | 3.3 | 3700 | 220 | 12.5 |
| White Fir | 10.0 | 585 | 317 | 10.4 |
| White Pine (Wis.) | 5.0 | 1600 | 195 | 13.3 |
| Sitka Spruce | 6.1 | 1130 | 216 | 12.6 |
| S. White Cedar | 1.8 | 7400 | 140 | 15.6 |
| W.White Pine | 5.8 | 1190 | 221 | 12.5 |
| Red Spruce | 4.1 | 1800 | 162 | 14.6 |
| Shortleaf Pine | 4.5 | 1480 | 158 | 14.7 |
| Slash Pine | 4.9 | 1090 | 148 | 15.2 |
| Loblolly Pine | 7.0 | 540 | 144 | 15.4 |
| Lodgepole Pine | 3.8 | 1490 | 118 | 17.1 |
| Douglas Fir (NW) | 5.4 | 800 | 122 | 16.8 |
| Ponderosa Pine | 3.1 | 1900 | 100 | 18.5 |
| Jack Pine | 3.4 | 1680 | 108 | 17.8 |
| Longleaf Pine | 3.8 | 1150 | 93 | 19.2 |
| E. Cottonwood | 8.5 | 320 | 126 | 16.5 |
| Virginia Pine | 2.5 | 2240 | 68 | 22.4 |
| Oak (Central States) | 4.0 | 965 | 84 | 20.2 |
| N. Hardwood (Lake States) | 6.7 | 390 | 90 | 19.5 |

* d.b.h. = Diameter at Breast Height; Breast Height is defined as 4.5 ft or 1.3 meters above the ground.

coming through the gaps between the leaves in the first layer will cast no hard shadow at the location of the second layer, the sunlight will appear as a diffused light source with reduced intensity. By repeating the same tactics, more layers of leaves can be grown profitably until the diffused sunlight intensity falls below the 20% limit. In the monolayer strategy, a plant will grow as much non-overlapping leaves as possible in one layer. All the available sunlight will be intercepted by this layer, and a hard shadow will be casted on the ground. Leaf growth will not be possible below the monolayer of leaves.

Mathematically, the multilayer strategy can utilize the available sunlight more efficiently. Because the effective interception of light in consecutive layers forms a geometrical progression with a ratio of at least 1/2, the maximum leaf area per unit land area is limited. In nature, it is found that the multilayer strategy is generally followed by large trees and plants of higher ranking species. However, for the undergrowth in a forest, seedling trees, and other small plants, the monolayer strategy will gather light most efficiently for an individual plant because very low average light intensity prevails in such an environment. In Table 2, the leaf area and leaf mass for various important species of trees have been summarized. Most of the given values are obtained from the forestry literature by direct or indirect estimates. Their accuracy is only nominal. In Table 3, typical values of leaf area to ground area ratio for grains and grasses are tabulated. The average weight per unit area of grains and grasses has not been tabulated because the value varies greatly with plant density, moisture, and seasonal conditions. The overall value for the common field crops is estimated as approximately 5 to 15 ton/acre of fresh weight.

## 4.3 Alternating Flow Resistance

Direct measured values of alternating flow resistance of plants and foliages are not available in the literature. An attempt is made here to obtain indirect estimates of such values. As air flows through a porous acoustical material, the boundary layer buildup at the exposed surfaces of the matrix material provides the mechanism for momentum dissipation. In an ordinary commercial acoustical material, the exposed surface area per unit volume is in the order of 100 to 10,000 $ft^{-1}$. In Beranek (Reference 11), the alternating flow resistance for various types of acoustical material at various densities has been measured. It appears from these results of measurement that the functional dependence of the alternating flow resistance on density is practically the same for all materials. On a double-logarithmic scale, all the $R_1$ versus $\rho_m$ curves are parallel to each other. Their difference in point of origin is strongly related to the characteristic value of exposed area per unit mass for each given material. Some of the results given in Reference 11 are extrapolated for lower densities. The curves are shown in Figure 5. By using the nominal values of fiber diameter, the exposed area per unit solid mass has been estimated for the Aerocor Fiberglas materials at a density of 0.5 lb/cu ft, the minimum surface area per unit volume is about 112 $ft^{-1}$. Thus, the alternating flow resistance can be replotted as a function of exposed surface area per unit volume (see Figure 6). In Reference 11, data

TABLE 2

LEAF WEIGHT AND LEAF AREA FOR VARIOUS FOREST TREE SPECIES

| Species | Height, ft | Estimated Effective Canopy Height, ft | Leaf Dry Wt Ton/Acre | Leaf Fresh Wt Ton/Acre | Estimated Leaf Density, $kg/m^3$ | Leaf Area Ratio |
|---|---|---|---|---|---|---|
| Ash | 60 | 40 | 1.20 | 5.70 | 0.106 | 4.5 * |
| Beech | 80 | 50 | 1.40 | 6.65 | 0.099 | 5.9 * |
| Birch | 75 | 50 | 1.10 | 5.20 | 0.078 | 4.1 * |
| Gum | 40-80 | 40 | 0.80 | 3.80 | 0.071 | 2.9 * |
| E. Hemlock | 60 | 40 | 1.70 | 5.70 | 0.106 | 3.8 |
| Oak | 80 | 40 | 0.98 | 4.65 | 0.069 | 3.1 * |
| Oak & Sourwood (Tennessee) | 50 | 30 | 1.30 | 6.18 | 0.139 | 4.7 * |
| Eastern Larch | 50 | 30 | 1.20 | 4.00 | 0.090 | 3.1 |
| Scots Pine | 75 | 45 | 2.80 | 7.00 | 0.104 | 6.5 |
| Red Pine | 80 | 45 | 4.50 | 11.25 | 0.185 | 13.1 |
| White Pine | 120 | 45 | 4.50 | 11.25 | 0.185 | 12.0 |
| Spruce | 110 | 45 | 4.80 | 12.00 | 0.196 | 12.6 |
| Norway Spruce | 100 | 45 | 5.75 | 14.40 | 0.236 | 13.0 |
| Silver Fir | 80 | 45 | 6.60 | 16.50 | 0.270 | 12.9 |
| Douglas Fir | 120-300 | 60 | 7.60 | 19.00 | 0.232 | 27.1 |

* For broadleaf trees, the area is measured only on one side of the leaf.

TABLE 3

LEAF AREA TO GROUND COVER AREA RATIO
FOR GRAINS AND GRASSES

| Species | Leaf Area Ratio * |
|---|---|
| Proctor Barley | 8.1 |
| Winter Wheat | 6.2 |
| Spring Wheat | 4.1 |
| Herta Barley | 3.7 |
| Rice | 10.2 |
| Sugar Cane | 11.8 |
| Corn | 8.5 |
| Clover Grass | 5.4 |
| Reed Canary Grass | 3.7 |

* The area is measured on only one side of the leaf.

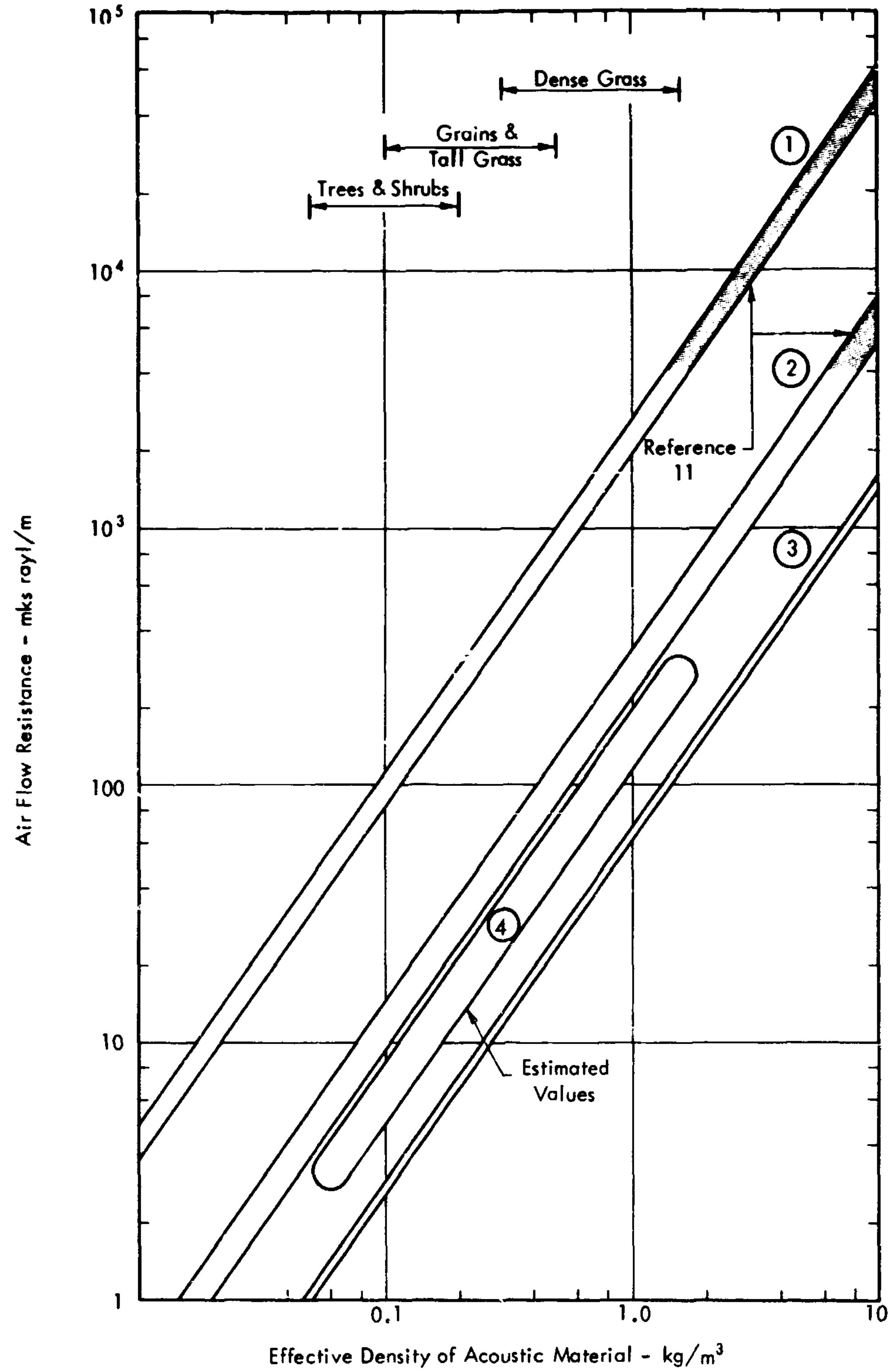



Figure 5. Air Flow Resistance as a Function of Acoustic Material Density. Materials shown in this figure are: 1 - PF 105 XAA Fiberglas (1950); 2 - Aerocor Fiberglas (1954); 3 - Johns Manville Spintex (1954); and 4 - Canopy of Forest, Grain Crop, and Grass.

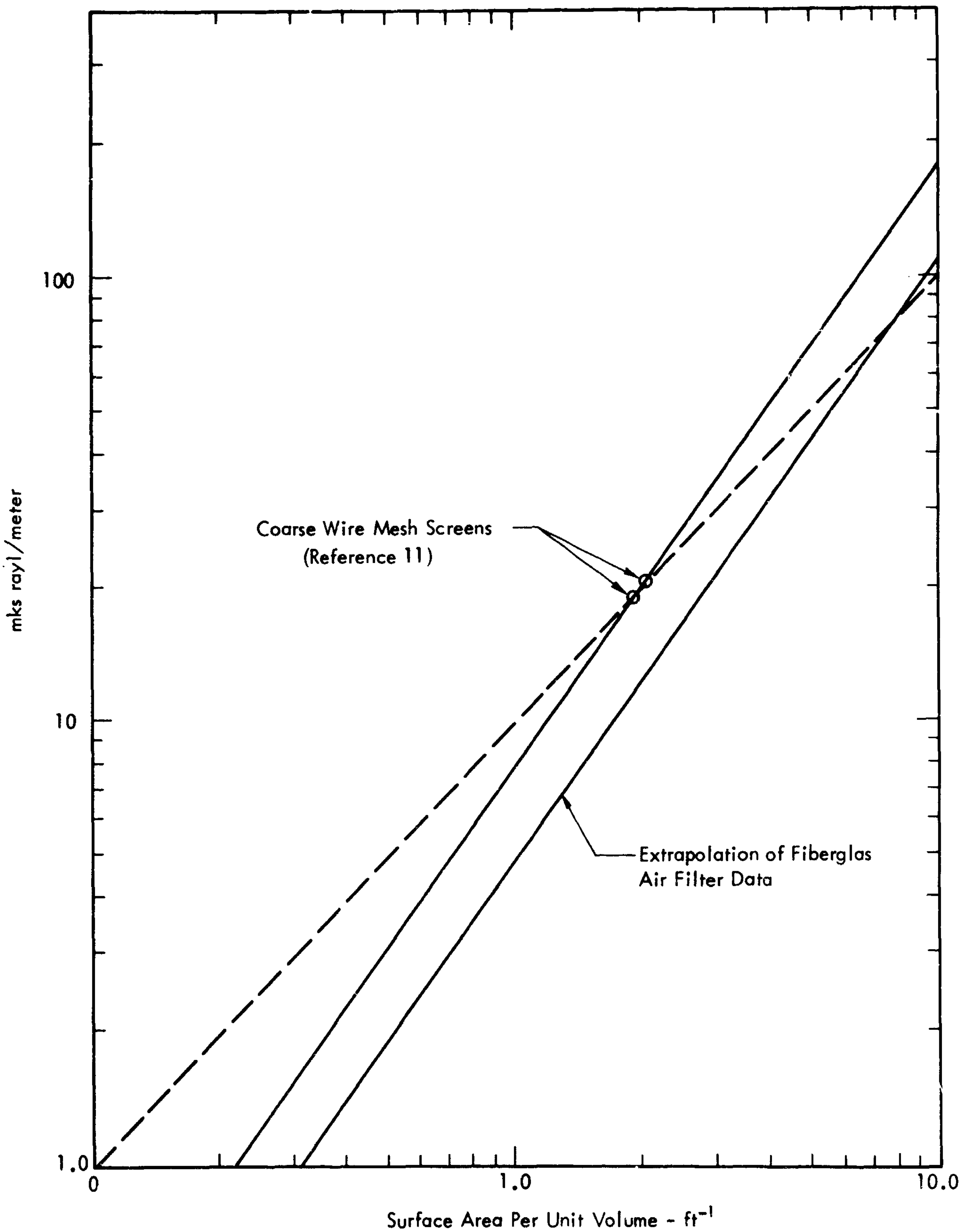



Figure 6. The Alternating Air Flow Resistance as a Function of Leaf Area Per Unit Volume

has also been given for the flow resistance of coarse wire screen meshes. If one assumes that the exposed surface area of the wire mesh were distributed not at the plane of the mesh, but throughout a layer of unit thickness, then the corresponding flow resistance value can be represented as a data point in Figure 6. The value of flow resistance for the coarse wire mesh is chosen because the distance between wires is significantly large such that the boundary layers on neighboring wires are independent of each other. By drawing a line through these data points and parallel to the alternating flow resistance curve of the Aerocor fiberglas, another estimate of the flow resistance can be established. It should be noted that the flow resistance is proportional to the 1.34 power of the value of surface area per unit volume. In acoustical materials commonly used for noise control, both the fiber size and the dimension of the air passage are relatively small. The boundary layers on neighboring fibers merge rapidly. Thus, the friction loss owing to boundary effects would resemble those of pipe flows. However, for surface areas with very low densities, the boundary layers on different surfaces may remain independent of each other at all times. In this case, the flow resistance should be directly proportional to the surface area in a unit volume. This postulation is represented by the dash line in Figure 6. Within the range of interest of the present study, the differences among the above three estimates are rather small.

According to the values of leaf area ratio and canopy thickness for various plant species, the leaf area per unit volume can be estimated. The typical ranges of values are given in Figure 7. In some cases, the exposed surface area for stems and branches may account for a significant portion of the total surface area in the canopy. It depends on the total volume of wood and the average branch and stem sizes. Such dependences are given in Figure 8. By using Figures 6 through 8, one can readily estimate the alternating flow resistance of a given type of plant canopy.

## 4.4 Other Parameters and Considerations

There are three more parameters remaining to be considered: the volume coefficient of elasticity of the porous acoustical material, Q; the volume coefficient of elasticity of air, K; and, the structure factor, k. Since the porosity is extremely close to one, the value of k can be assumed to be 1.0 for all cases. It is not necessary to know the exact value of Q in the Beranek equations. Since both the material density and the flow resistance are provided by the leaves, the plant canopy is assumed to be a soft porous acoustical material, i.e., $K > 20Q$. For the forest canopies, the foliage density is relatively low. The parameter K is assumed to take its value under isentropic conditions. For dense plantation of grain crops or grasses, K can possibly take its value somewhere between isothermal limit and isentropic limit. Further studies are definitely required.

According to the above defined ranges of structural parameters, the acoustic properties of ground cover materials have been estimated. Computations are made assuming both conditions where the matrix structure can either be rigid or be soft. The obtained values for the refraction coefficient, n, and the internal transmission loss coefficient, $\alpha$, are plotted as a function of frequency.

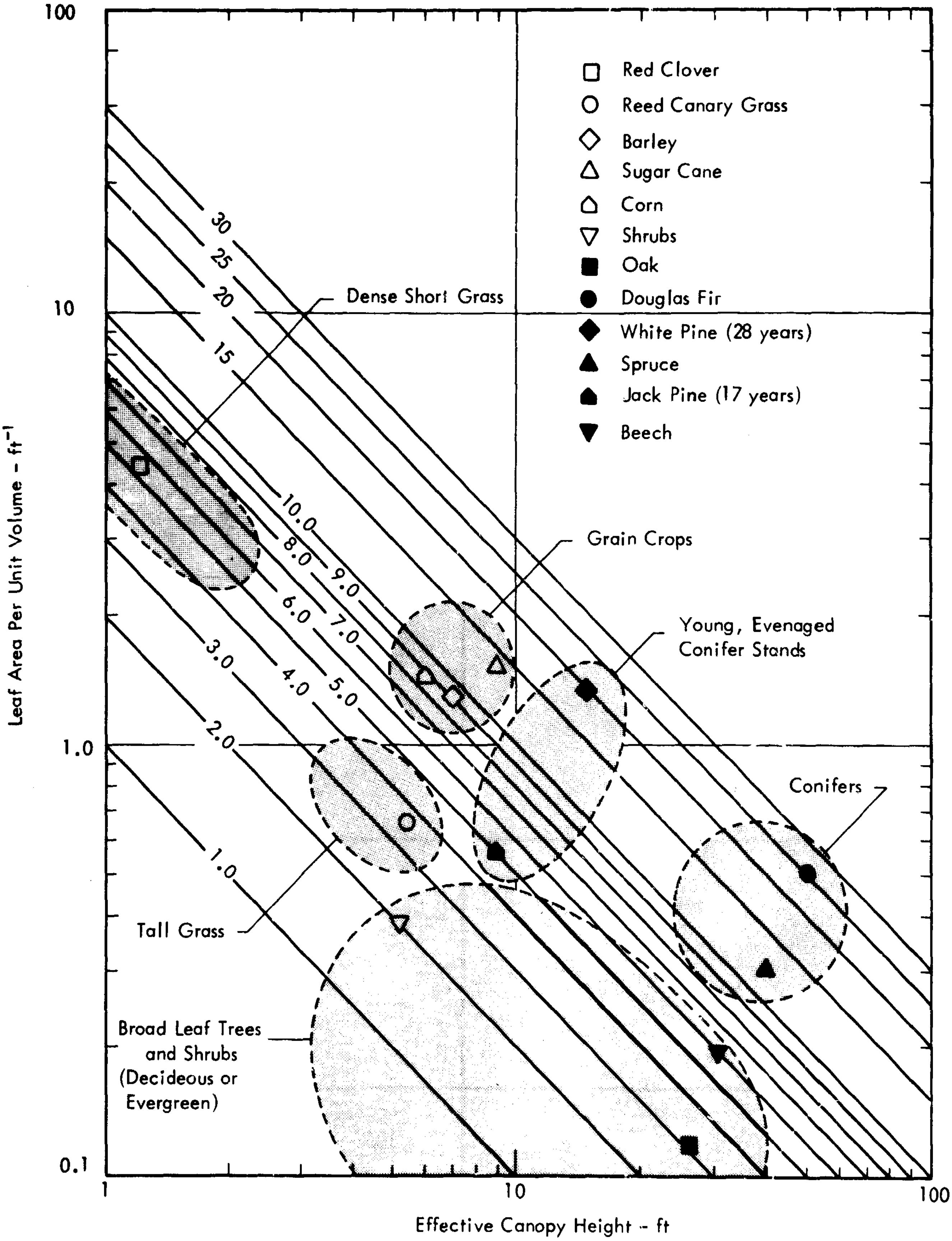



Figure 7. Leaf Quantity for Various Plant Species

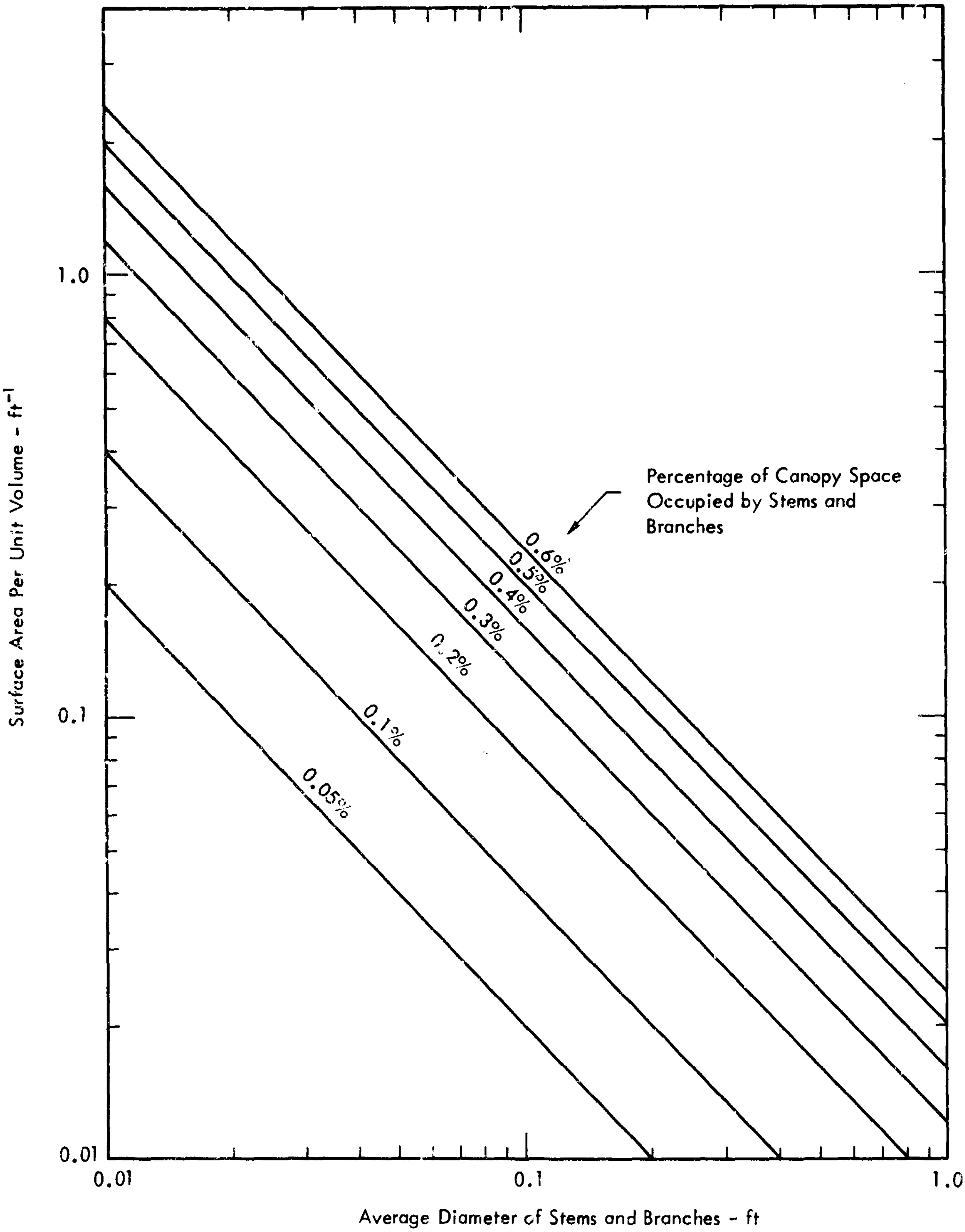



Figure 8. Exposed Surface Area of Tree Stems and Branches

The results for the soft matrix materials are given in Figures 9 and 10. According to the Beranek model of acoustical materials with a soft blanket, the velocity of sound in the low frequency range is greatly reduced by the effective material density. For higher frequencies, the sound wave can propagate in the acoustical material at nearly the speed of sound in free air. For the attenuation coefficient $\alpha$, the trend with frequency is just the opposite. Since the matrix rides with the air flow at low frequencies, very little friction is generated through friction between the air flow and the matrix. Hence, $\alpha$ is small in the low frequency range. As the frequency increases, the inertial forces will keep the matrix material stationary, and thus the relative motion between the matrix and air increases. Consequently, $\alpha$ increases with frequency, and reaches a limiting value for very high frequencies.

Values of the refraction coefficient, n, for materials with a rigid matrix are plotted in Figure 11. For a rigid matrix acoustical material, the acoustical properties do not depend on $\rho_m$. Hence, $R_1$ is the only significant variable. The dependence of $\alpha$ on frequency is very weak for acoustical materials with a rigid matrix. It remains about constant for all frequencies. The value of $\alpha$ for an acoustical material with a rigid matrix is approximately the same as the limiting value of $\alpha$ at high frequencies for a soft matrix material with the same value of $R_1$.

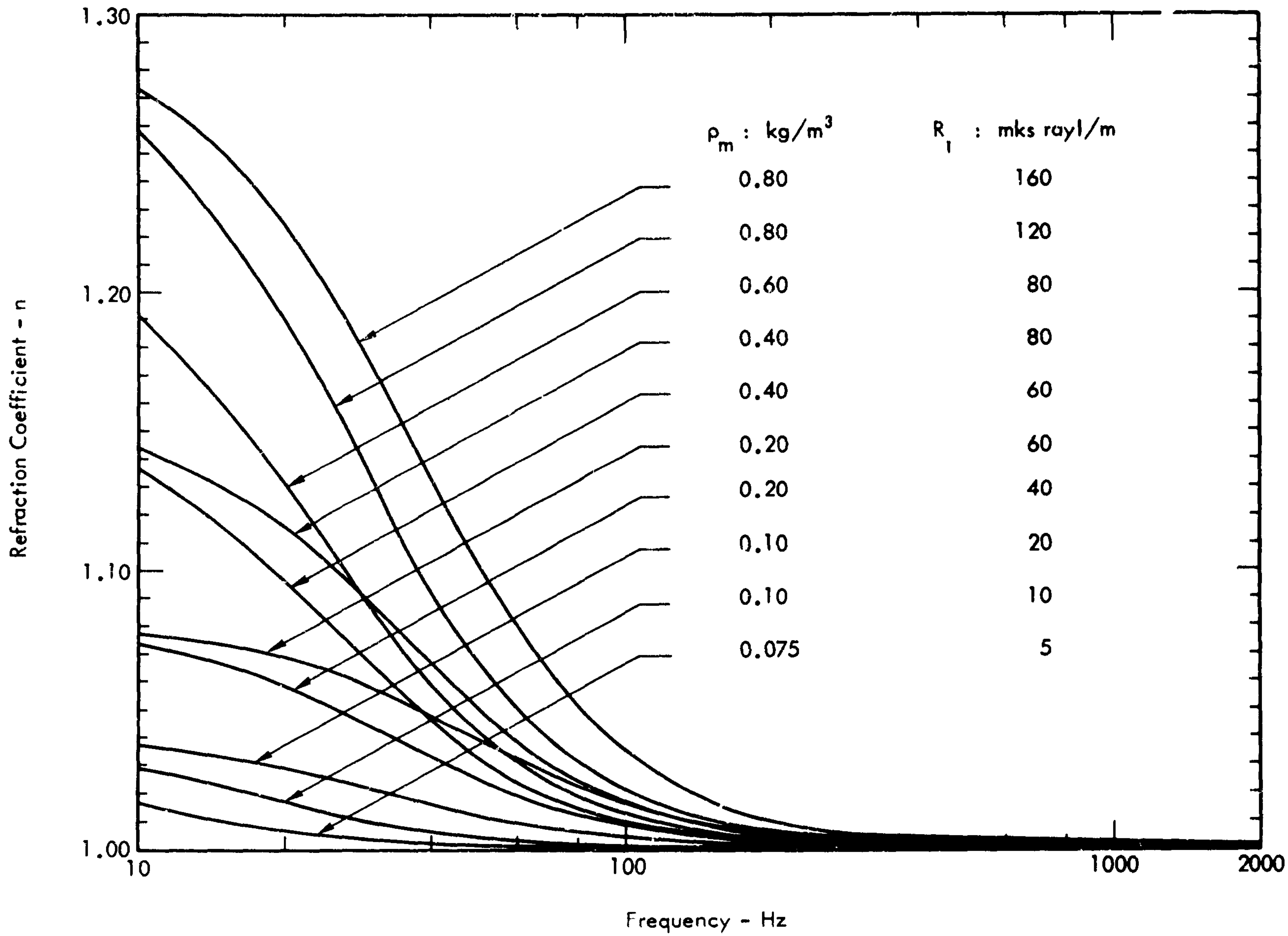



Figure 9. Refraction Coefficient Versus Frequency. Each curve represents a soft acoustic material with given values of effective density and air flow resistance.

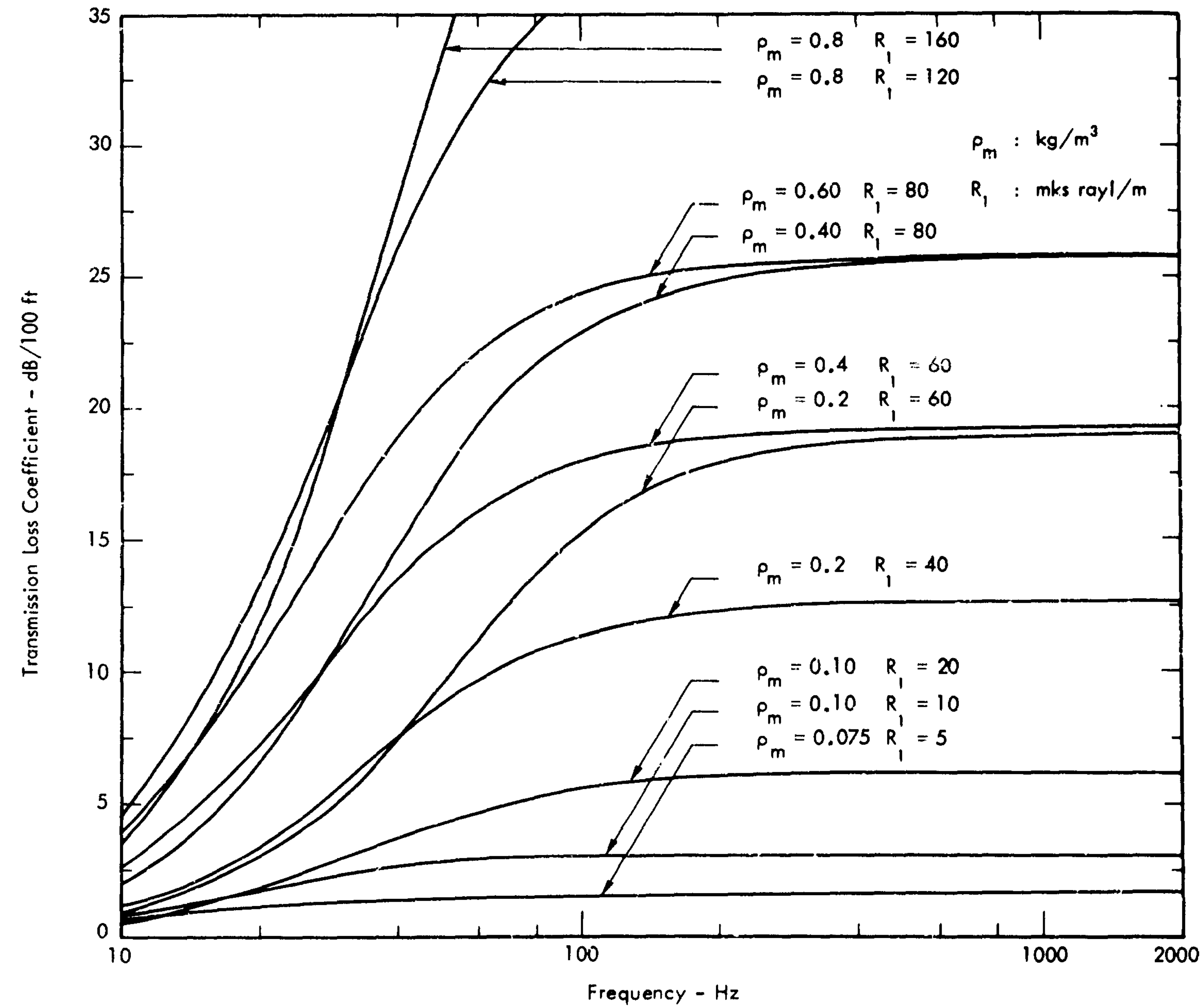



Figure 10. The Internal Transmission Loss Coefficient for Various Soft Acoustical Materials

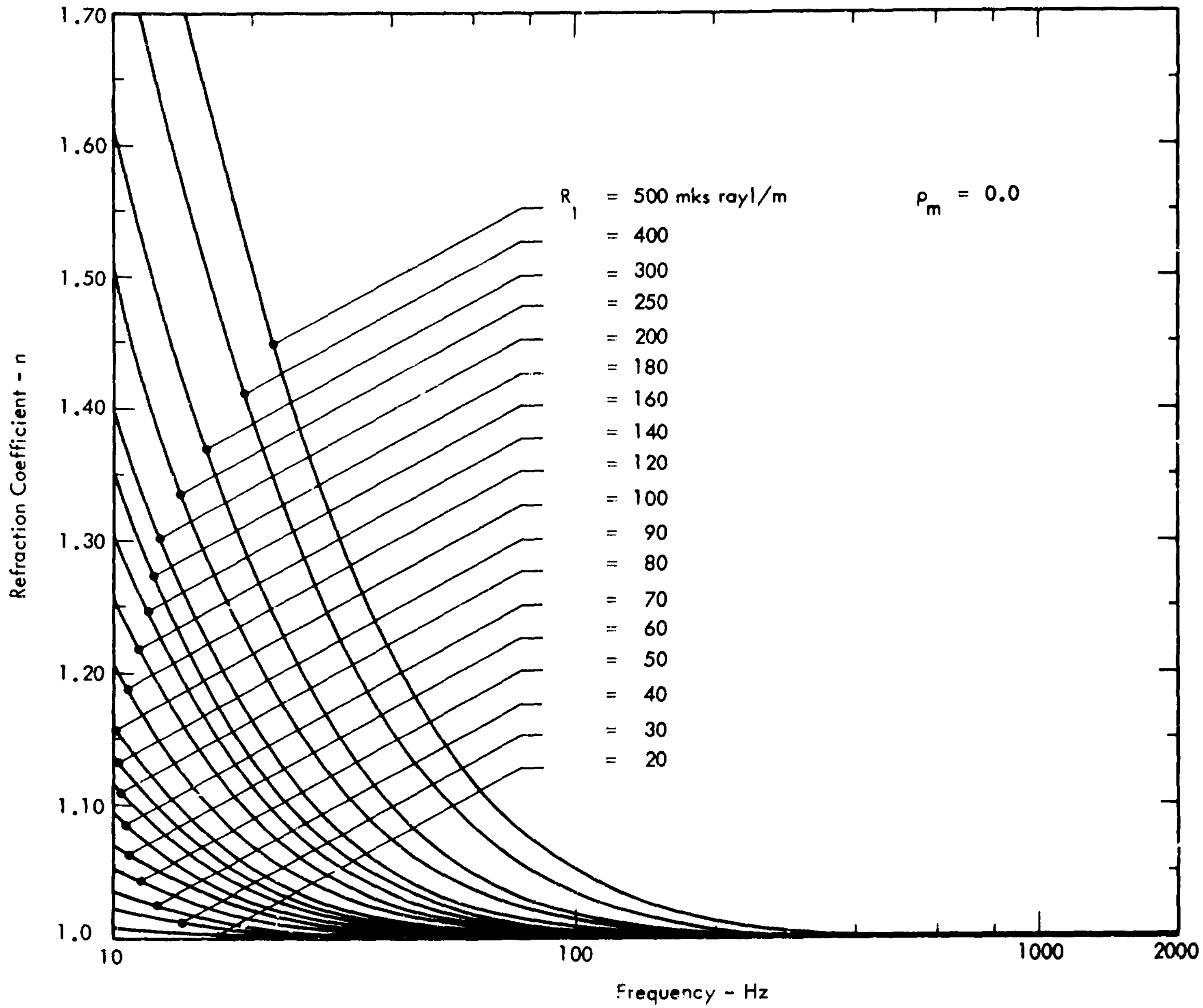



Figure 11. Refraction Coefficient Versus Frequency. Each curve represents a rigid frame acoustical material with a given air flow resistance.

## 5.0 PREDICTION OF ABSORPTION SPECTRA FOR VARIOUS TYPES OF NATURAL GROUND COVER

In the previous section, the acoustic properties of canopies of trees, grain crops, and grass fields have been estimated. According to these values of refraction coefficient, acoustic admittance ratio, and the internal transmission loss coefficient, the ground absorption spectra can be calculated.

The structural properties of natural ground covers, and consequently their acoustic parameters, fall into three recognizable ranges:

- Trees and shrubs
- Grain crops and tall grasses
- Short, dense grasses

For trees and shrubs, the fresh leave weight per acre of ground area is between 4.0 to 19.0 tons per acre (Table 2). The leaf area to ground area ratio is generally in the range of 5 to 25. For tall matured forests, the effective thickness of the closed canopy is approximately 50 ft. Therefore, the effective density for acoustic purposes is in the order of 0.075 to 0.200 $kg/m^3$; and the leaf area per unit volume is in the order of 0.1 to 0.5 $ft^{-1}$. For young tree stands, tree species which are short by nature, and shrubs, the effective thickness of the canopy can be 10 to 20 ft. At the same time, the leaf mass and the leaf area ratio remain practically the same as the tall forests. Hence the effective leaf density is in the order of 0.20 to 0.6 $kg/m^3$; and the leaf area per unit volume is in the order of 0.30 to 2.5 $ft^{-1}$. In the summer, the leaf area dominate the total surface area in the canopy of a deciduous forest. In the fall or winter, all the leaves will be fallen. The only exposed surface area will be those of the stems and branches. For a forest canopy with a large portion of small branches, the total surface area can be as high as 0.4 $ft^{-1}$.

For grain crops and tall grass pastures, the structural parameters fall into an entirely different range. The canopy height is commonly between 4 to 8 ft. The fresh weight of the leafy portion of the plant is between 5 to 8 tons per acre, depending on the species and the plant number density. The leaf density is approximately 0.4~1.0 $kg/m^3$. Since all the leaf shapes in grains and grasses are flat, the effective surface area for acoustic resistance should be counted on both sides of the leaves. Hence the effective leaf area ratio is twice that which is quoted in the agricultural literature where only one side of the leaf is measured for photosynthesis purposes. The estimated leaf area per unit volume is, therefore in the order of 1.0 to 4.0 $ft^{-1}$.

The highest foliage mass density and leaf area per unit volume can be found in grass fields with an overall thickness of less than 24 inches. The effective density is in the order of 1.0 to 2.0 $kg/m^3$. The two-sided leaf area ratio is approximately 10. Hence, the leaf area per unit volume has a value between 5.0 and 10.0 $ft^{-1}$.

The ranges of parameters for the above three classes of vegetation are summarized in Table 4.

Computer programs have been written to perform both the calculation of acoustical properties of the ground cover and the computation of sound absorption spectrum using the analysis given in Section 2.0. In the computation of the sound absorption spectrum, three acoustical parameters are required: the refraction coefficient, n ; the specific admittance ratio of the ground cover relative to air, $\beta_1$ ; and the normal admittance ratio of the ground surface, $\beta_2$. The parameters n and $\beta_1$ are generated by the computer program according to the given structural properties of the ground cover. Two values of $\beta_2$ are assumed arbitrarily. For a forest stand, $\beta_2$ is assumed to be 0.5 if the undergrowth is relatively dense; it is assumed to be 0.2 if the undergrowth is sparse and the floor of the forest is covered with only a shallow layer of fallen leaves and branches. For grain and grass fields, the ground surface is expected to be a loose top soil in most cases. Such a surface has a relatively high acoustic impedance. Hence, the value of $\beta_2$ is taken to be 0.2.

For forest canopies, the ground absorption spectra for three sets of representative acoustic parameters have been computed. The effective canopy thickness, instead of the overall height of the forest itself, is chosen to represent the layer thickness of the acoustic material as defined in the theory. In these computations, the receiver is located either above the canopy, or immediately on top of the canopy. Computation has not been made for receiver locations in the canopy, although in practical situations the observer may very well be standing on the floor of a forest and listening to the noise produced by a low-flying aircraft. Under such practical conditions, one can safely assume that the minimum excess attenuation is represented by the values predicted for an observer located immediately on top of the forest canopy.

The computed results are given in Figures 12 through 14, and Tables 5 through 19. For tree canopies with very low density and air flow resistance, the acoustical effect of the canopy on wave propagation is obviously very low. In Figure 12, the absorption spectrum for small canopy thicknesses exhibits clearly the characteristics of interference effect for wave reflection next to a solid wall. It appears also that the tree formations offer very little attenuation to sound at higher frequencies, owing to the ground effect. The attenuation to higher frequencies is significant only if the sound propagates through the leafy canopy itself. Significantly large attenuation is indicated by the transmission loss coefficient, $\alpha$ , as given in Figure 10. In the winter time, perhaps very little ground attenuation effect can be expected from a deciduous forest stand.

The absorption spectrum has also been computed for several densities and thicknesses of grain and grass canopies. The results are given in Figures 15-19 and Tables 20-29. The range distances and sound sources height have been limited to values at which field measurements are commonly conducted. These tables and graphs are considered to be reasonably accurate. They can be employed for preliminary estimates of ground absorption of sound in actual field conditions.

TABLE 4

MECHANICAL PROPERTIES OF THREE CLASSES OF PLANT CANOPIES

| Type of Ground Cover | Foliage Density kg/m | Surface Area Per Unit Volume $ft^{-1}$ | Air Flow Resistance mks rayl/m |
|---|---|---|---|
| Trees & Shrubs | | | |
| Tall Canopy | 0.075 ~ 0.200 | 0.1 ~ 0.50 | 1.0 ~ 5.0 |
| Short Canopy | 0.20 ~ 0.60 | 0.3 ~ 2.50 | 3.0 ~ 28 |
| Stems & Branches | 0.0 | 0.05 ~ 0.40 | 0.0 ~ 4.0 |
| Grain Crops & Grasses | 0.40 ~ 1.00 | 1.00 ~ 4.0 | 8.0 ~ 50 |
| Dense Short Grass | 1.0 ~ 2.0 | 5.0 ~ 10.0 | 50 ~ 120 |

If the source height were different from those as given in the computed conditions, the excess attenuation can be adjusted by using the formula

$$E = E_0 - 20 \log_{10} (H/H_0)$$

where $E_0$ is the excess attenuation corresponding to a height of $H_0$, and $E$ denotes the required excess attenuation corresponding to a height of H. However, the above equation is accurate only if both $H_0$ and H are at least one layer thick above the top of the ground cover. In the tabulated results of the absorption spectrum, the excess attenuation is given at various range distances. It can be noted from these results that the excess attenuation increases at 6 dB per doubling the range distance in the far-field, and increases at a somewhat smaller rate in small range distances from the sound source.

## 6.0 CONCLUSIONS AND DISCUSSIONS

There are certain limitations to the present prediction scheme. First of all, the Beranek model of porous acoustical material is a reliable method for the estimates of acoustical properties of the ground cover, yet it is not the only available approach. For example, in the high frequency range, the transmission loss of sound through a plant canopy may depend on the diffraction effect of leaf surfaces. A recent study by Aylor (Reference 13) has shown remarkable agreement between theory and experiment for sound transmission losses through high density broadleaf canopies. In the approach taken by Aylor, diffraction and penetration of sound through the leaf mass are considered to be chief mechanisms. The improvement of the definition of acoustical properties for ground cover material can be achieved by both theoretical and experimental approaches. The experiments may include the measurement of physical properties of leafy canopies, from which the acoustical properties can be estimated, or the direct measurement of the acoustical properties of the plant canopy. The improved knowledge of ground cover acoustical properties can definitely be used advantageously in the present layered media approach of dealing with the ground absorption of sound.

From the computations of Section 4.0, it is obvious that all the ground cover materials have very small acoustical "density" as compared to ordinary architectural acoustical materials. However, the lack of acoustical "density" is somewhat compensated by the large spatial dimensions often encountered in field conditions. From the computed results, it becomes apparent that the ground absorption effect is significant only if the range distance is larger than approximately 25 times that of the height of the sound source. At range distance of less than 10 times that of the height of the sound source, not only the absorption is small in value, but also the spectrum is irregular and exhibits no apparent trend. It is not clear whether the irregularity is caused partly by nature of the ground absorption effect or that it is caused entirely by the inaccuracy of the mathematical model in the near field. Fortunately, such near field conditions are seldom of practical interest for noise control studies.

Inspite of the limitations as mentioned above, the computed results seem to agree well with experimental evidences. It was pointed out in the earlier publication under this program (Reference 1) that the predicted ground absorption effects agreed closely with the result of laboratory-scaled experiments. In Section 5.0, there are several sets of computations where the input parameters are typical of dense grasses and low bushes. The height of the source and the receiver is assumed to be between 5 to 10 ft; the thickness of the ground cover is from 6 in. to 6 ft; and the range distances are 250 and 500 ft. The spectrum shapes in the predicted cases are strikingly similar to those measured in the field. The peak is located between 100 and 400 Hz, and the excess attenuation is close to 15 dB for all cases. Similar values of ground absorption under similar conditions have been observed before (References 14 and 15). It is important to note also that the transmission loss coefficient for wave propagation through the canopy itself has been computed for a range of values in Section 4.0. For conditions typical in a tree stand, $\rho_m = 0.225$ kg/m$^3$, and $R_1 = 20$ rayl/m. The computed

transmission loss coefficient is about 5.5 dB/100 ft. This value is very close to those observed previously by various authors (References 12, 16 and 17).

Several important trends have also been observed in this study. The peak of the absorption spectrum is governed by several principal factors: the height of the sound source*; the thickness of the ground cover layer; and, the acoustical properties of the ground cover and the ground surface. In previous computations by Ingard, the absorption peak is normalized with respect to the sound source height. The product of the wavenumber and the source height, kh, has a value of approximately 11.0. In the present study, the peak absorption frequency can be normalized against the layer thickness. It is found in the computations that the peak of the ground absorption frequency is dominated by the layer thickness, provided that the ground cover is sufficiently dense. The value of kh is between 3.0 to 10.0. For layers with very small density, such as the density of a deciduous forest, the influence of the height of sound source on the peak absorption frequency will remain significant.

The predictions of ground absorption of sound over ground cover with very large thicknesses, such as forest stands, remain to be compared with experiment measurement. However, it is reasonable to assume here that the predictions as given in Section 5.0 should serve well as an indicator of the expected ground absorption levels in actual field conditions.

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* According to the principal of reciprocity, the value of excess attenuation remains invariant if the positions of the sound source and the receiver are exchanged. Hence, it is not necessary to mention both the source height and the receiver height in the discussions.

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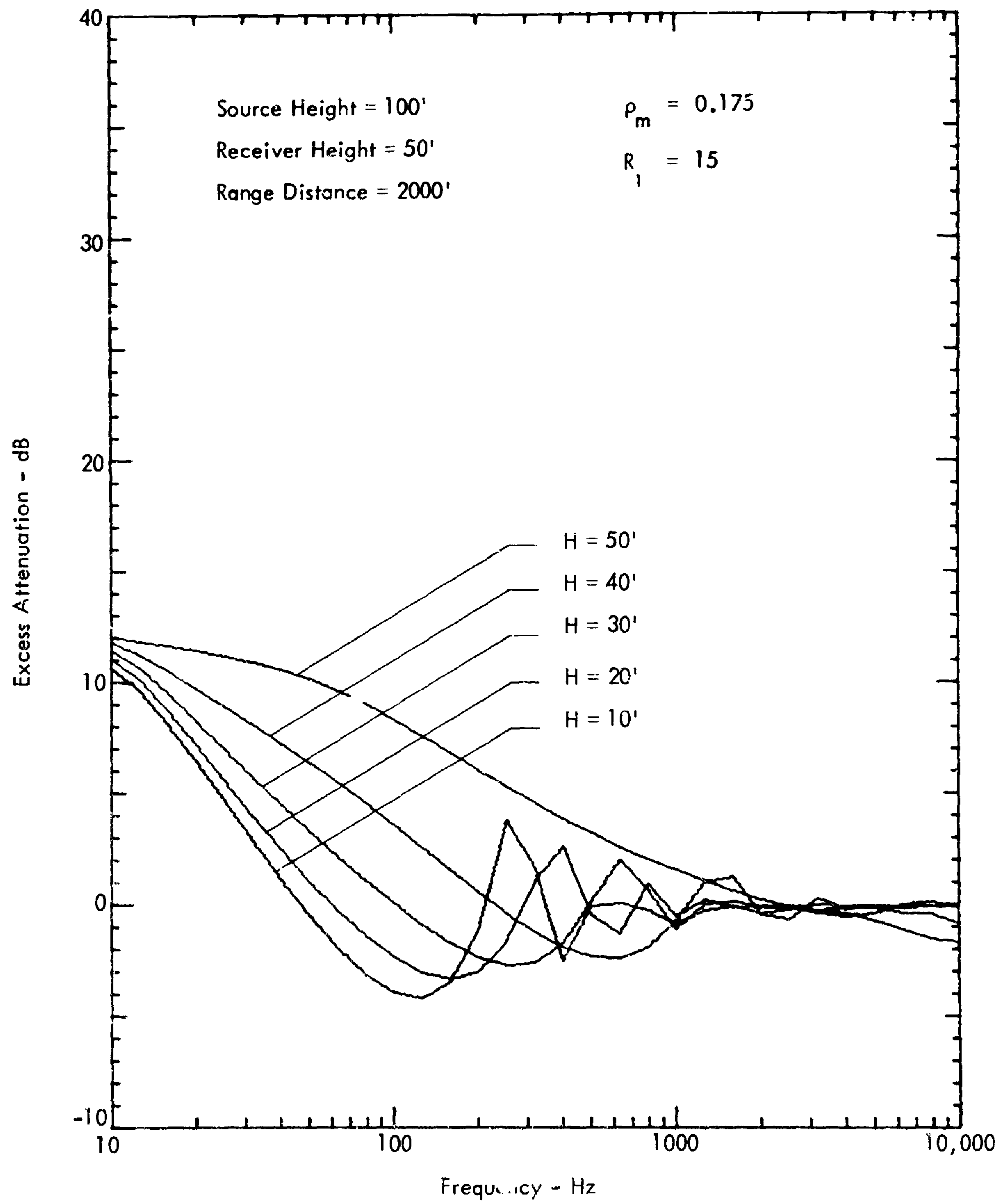


Figure 12. Ground Absorption Spectrum for Tree Stands at Various Canopy Heights. Heavy undergrowth is assumed; $\beta_2 = 0.5$; $\rho_m = 0.175$; $R_1 = 15$

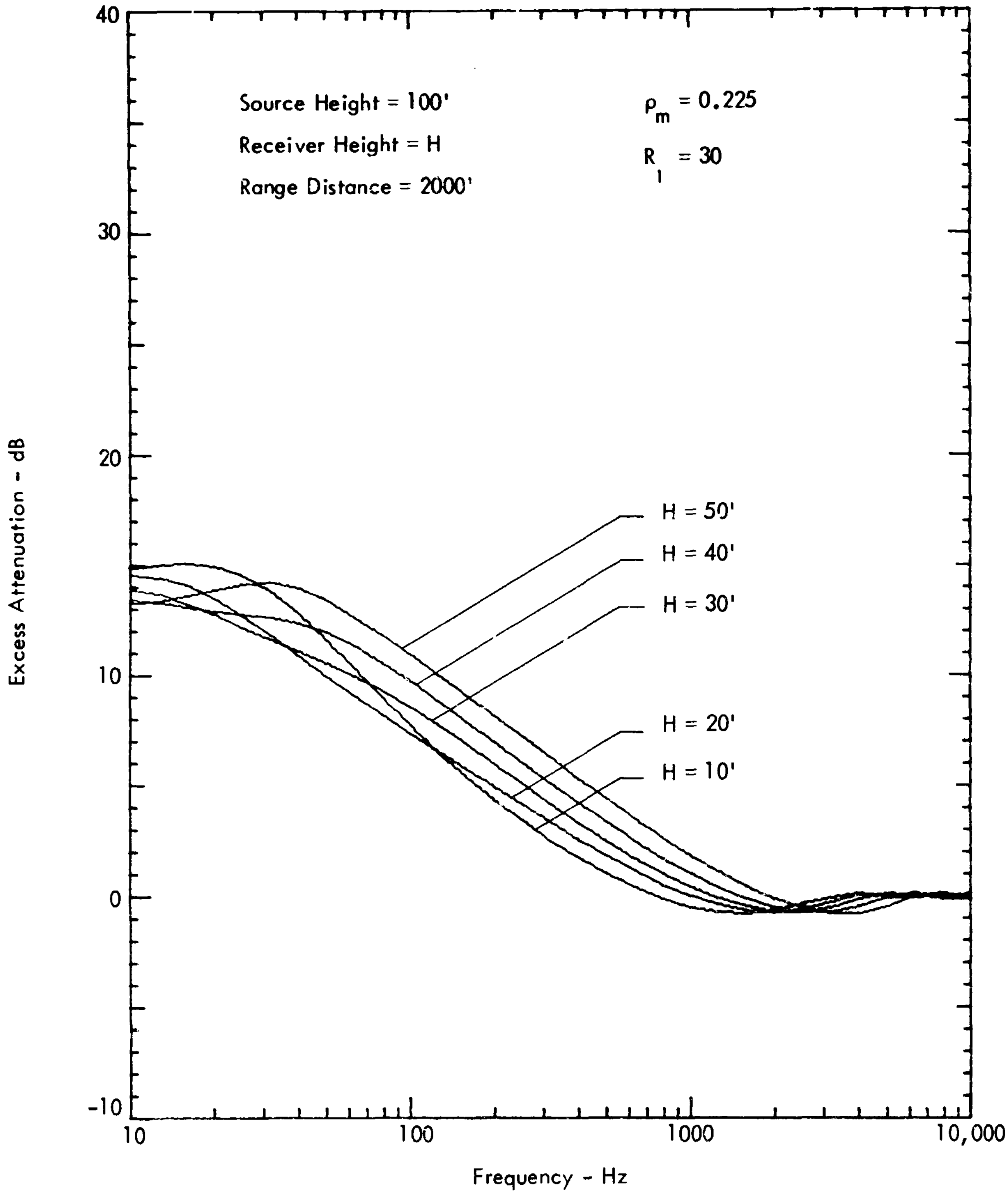


Figure 13. Ground Absorption Spectrum for Tree Stands at Various Canopy Heights. Heavy undergrowth is assumed; $\beta_2 = 0.5$; $\rho_m = 0.225$; $R_1 = 30$. The receiver is immediately on top of the canopy.

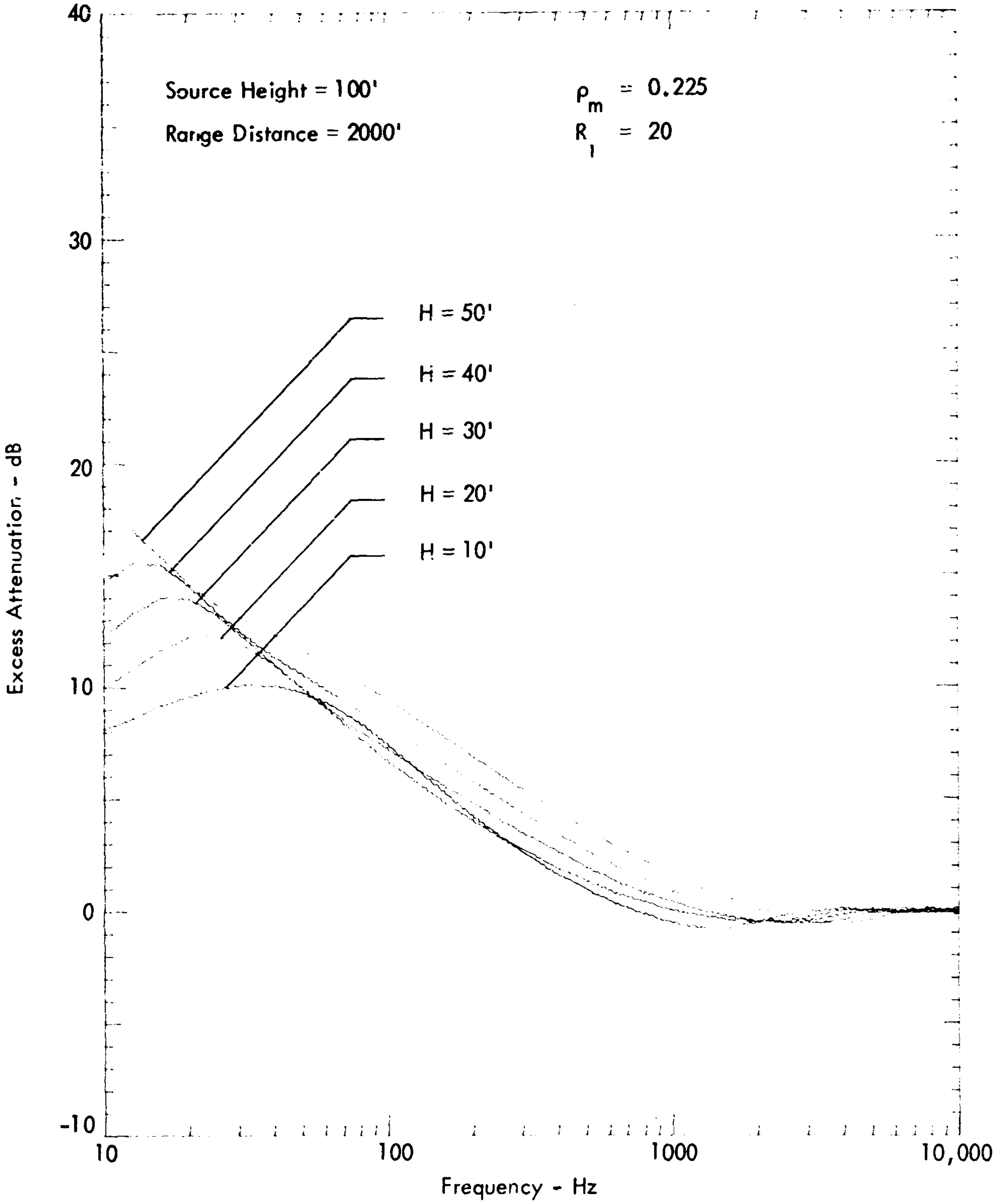


Figure 14. Ground Absorption Spectrum for Tree Stands at Various Canopy Heights. Sparse undergrowth is assumed; $\beta_2 = 0.2$; $\rho_m = 0.225$; $R_1 = 20$. The receiver is immediately on top of the canopy.

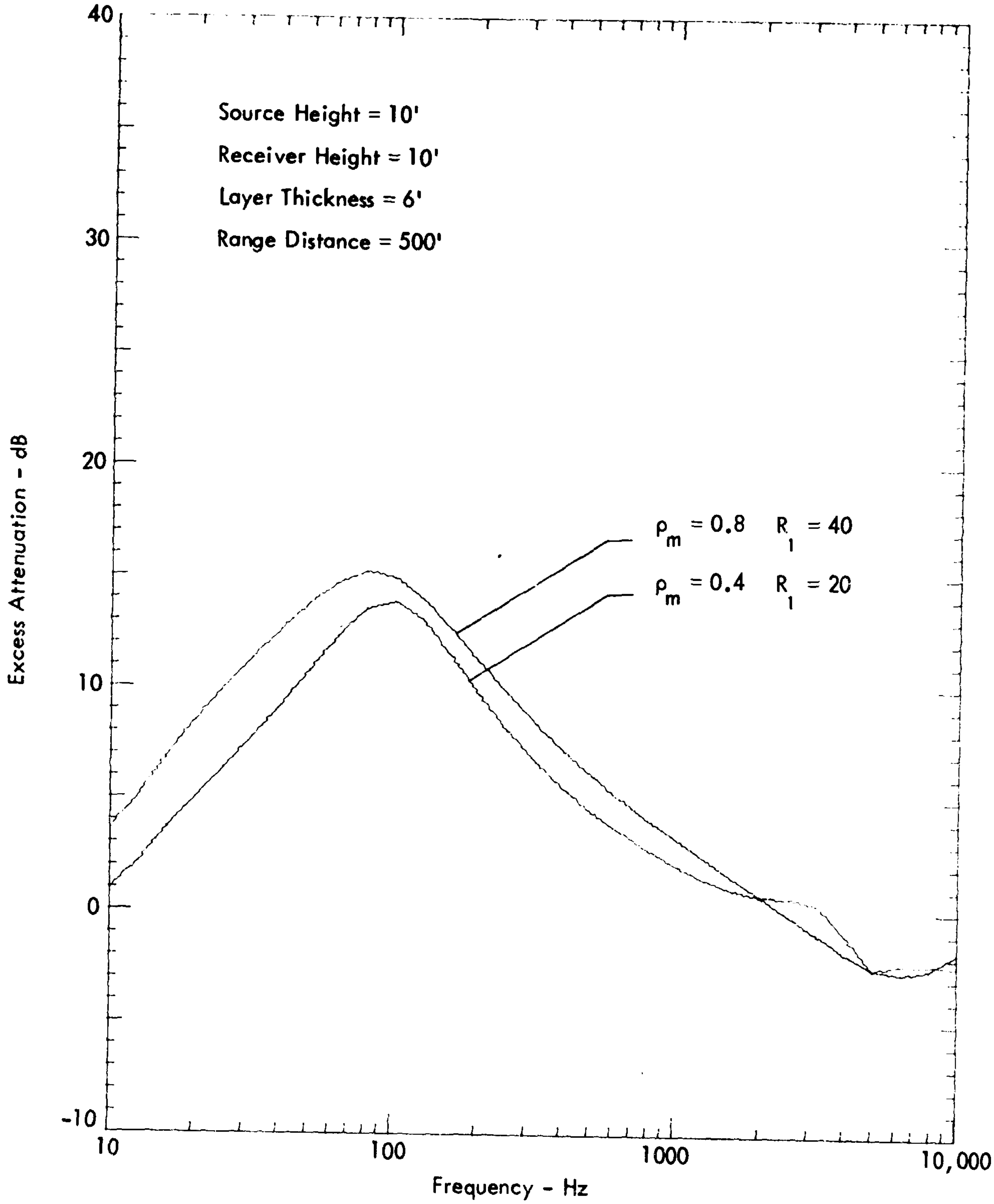


Figure 15. Ground Absorption Spectrum for Grains and Tall Grasses. Layer Thickness = 6 ft

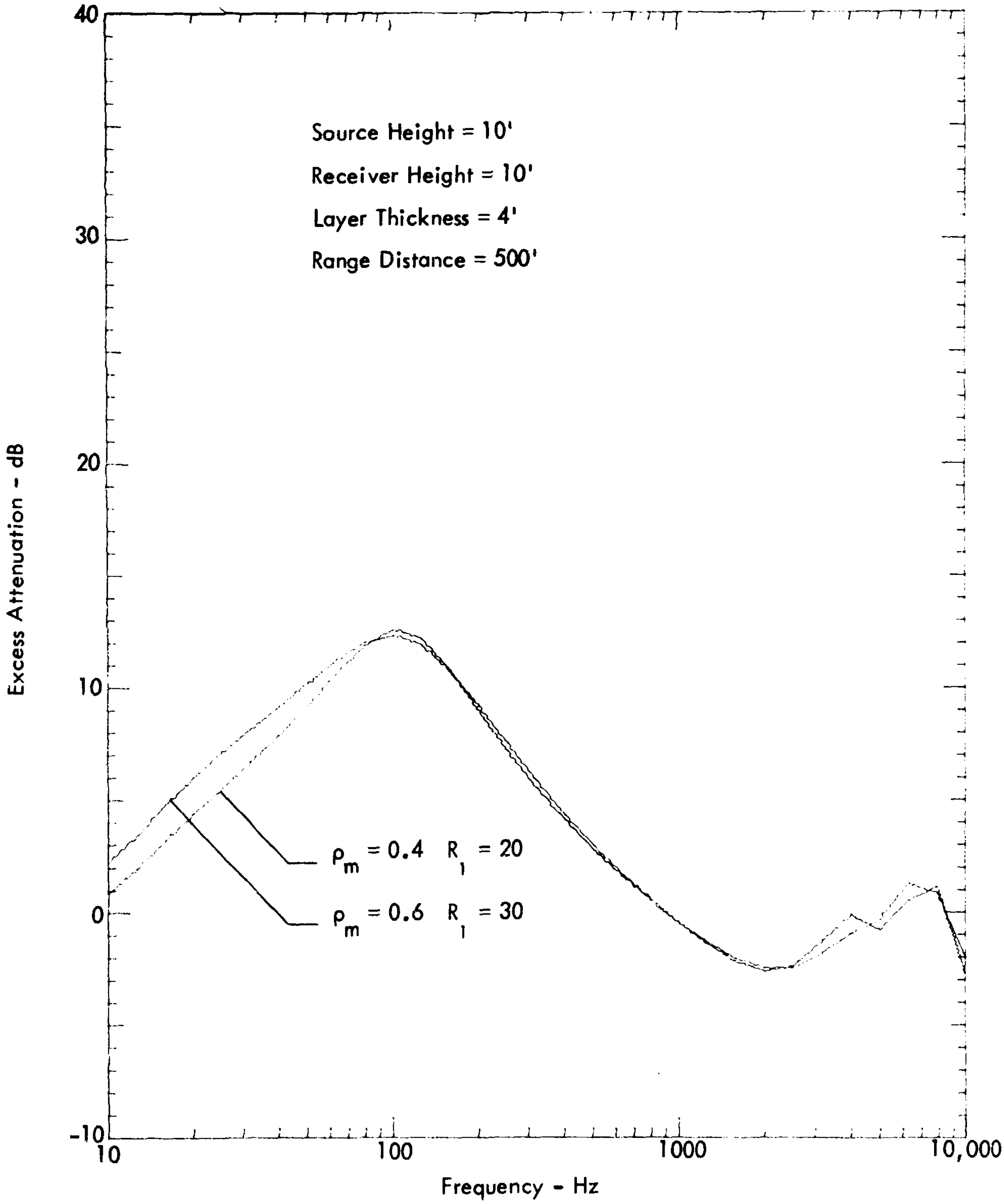


Figure 16. Ground Absorption Spectrum for Grains and Tall Grasses. Layer Thickness = 4 ft

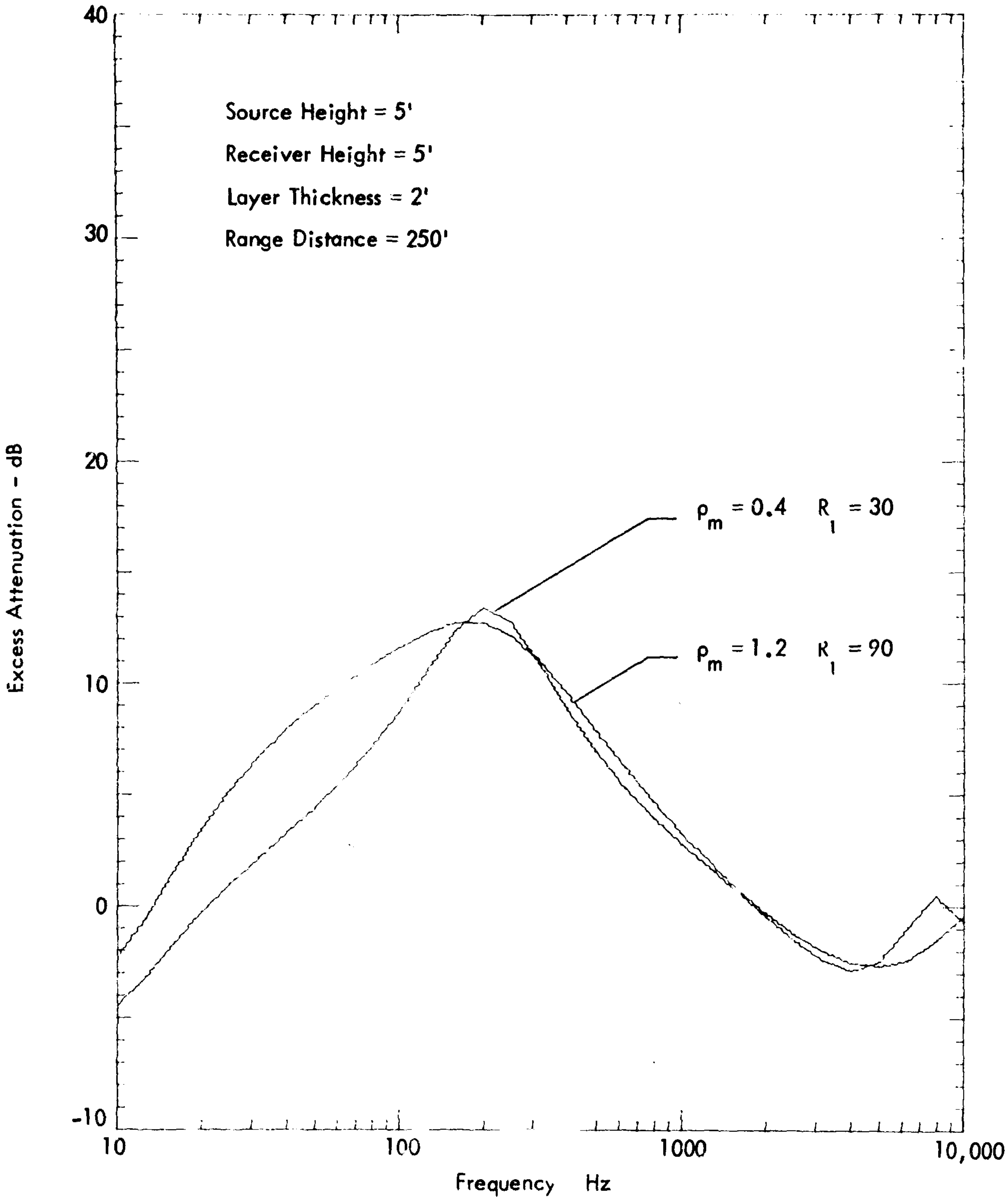


Figure 17. Ground Absorption Spectrum for Dense, Short Grasses.
Layer Thickness = 2 ft

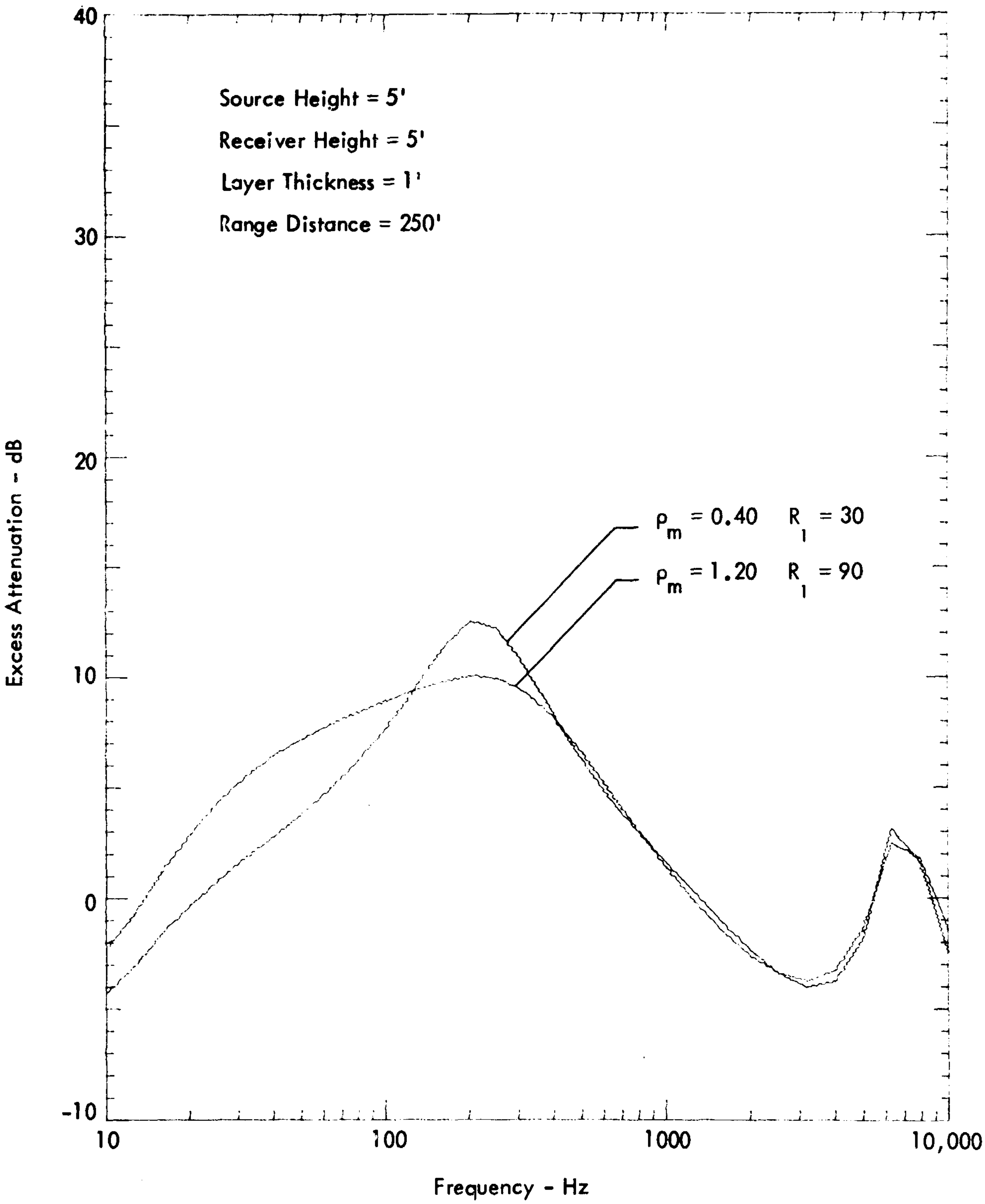


Figure 18. Ground Absorption Spectrum for Dense, Short Grasses. Layer Thickness = 1 ft

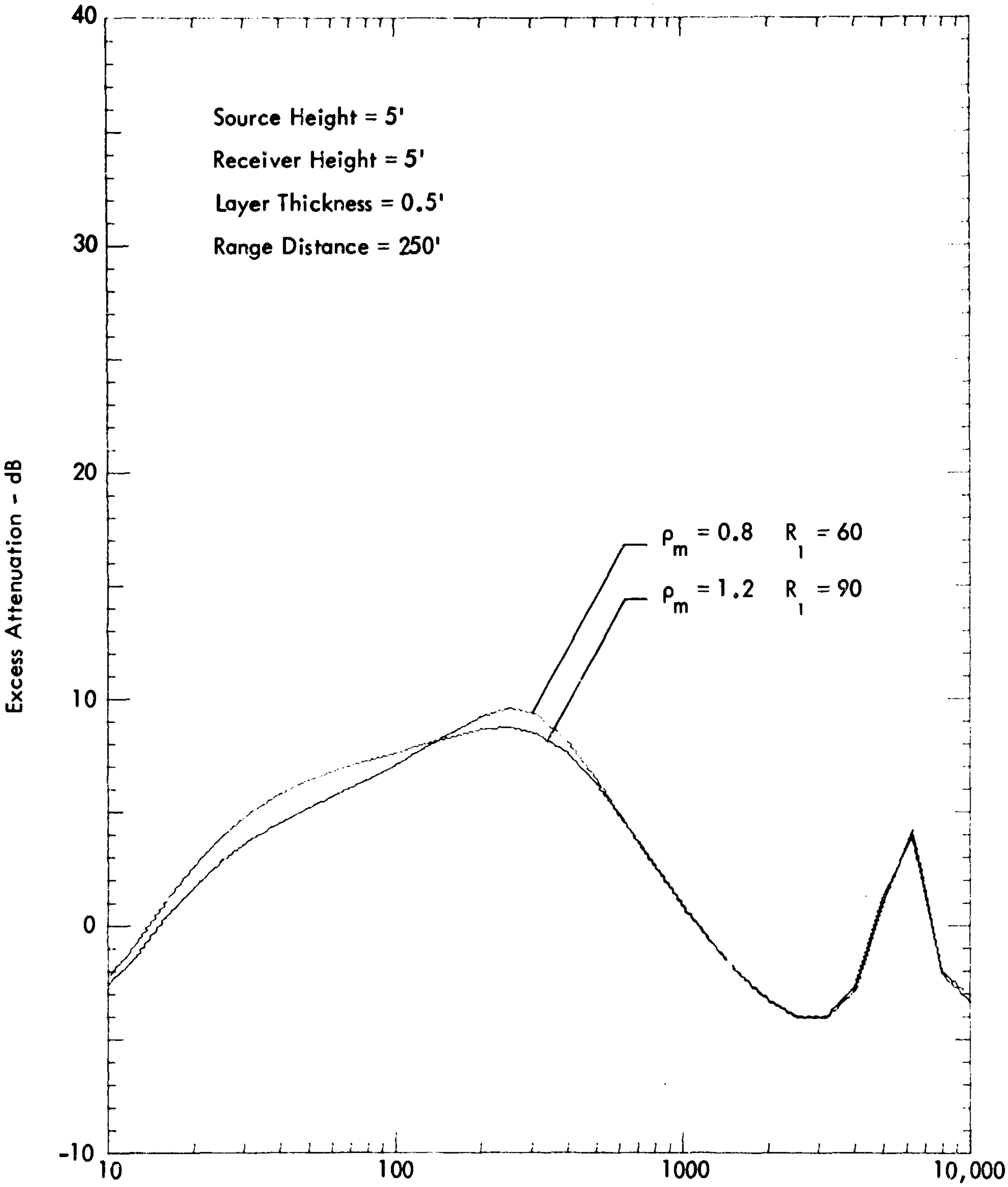


Figure 19. Ground Absorption Spectrum for Dense, Short Grasses. Layer Thickness = 0.5 ft

## TABLE 5
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.27400E+02
YSC =  0.10000E+01
YRE =  0.12180E+02
H   =  0.30440E+01
B2  =  0.50000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.39600E+00
R1  =  0.15000E+02
RM  =  0.17500E+00
Q   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 0.47 | 1.90 | 5.57 | 10.58 | 16.27 |
| 12.59 | 0.35 | 1.31 | 4.73 | 9.60 | 15.22 |
| 15.85 | 0.14 | 0.40 | 3.43 | 8.09 | 13.61 |
| 19.95 | -0.05 | -0.56 | 2.00 | 6.41 | 11.81 |
| 25.12 | -0.10 | -1.43 | 0.54 | 4.64 | 9.90 |
| 31.62 | 0.03 | -2.00 | -0.84 | 2.85 | 7.95 |
| 39.81 | 0.15 | -2.01 | -2.05 | 1.13 | 6.01 |
| 50.12 | -0.03 | -1.02 | -2.96 | -0.49 | 4.11 |
| 63.10 | -0.13 | 1.25 | -3.40 | -1.92 | 2.28 |
| 79.43 | 0.15 | 1.82 | -3.06 | -3.11 | 0.57 |
| 100.00 | -0.12 | -1.13 | -1.33 | -3.92 | -1.01 |
| 125.89 | 0.04 | -0.74 | 2.57 | -4.17 | -2.40 |
| 158.49 | 0.02 | 0.84 | 2.25 | -3.50 | -3.53 |
| 199.53 | -0.03 | -0.69 | -2.10 | -1.11 | -4.29 |
| 251.19 | 0.00 | -0.47 | -0.66 | 3.81 | -4.48 |
| 316.23 | -0.01 | -0.20 | 0.58 | 1.61 | -3.69 |
| 398.11 | -0.00 | -0.20 | -0.70 | -2.54 | -1.07 |
| 501.19 | -0.01 | -0.24 | -0.97 | -0.10 | 4.19 |
| 630.95 | -0.01 | -0.51 | -0.46 | 0.05 | 1.38 |
| 794.33 | -0.02 | -0.64 | -0.30 | -0.29 | -2.51 |
| 1000.00 | -0.03 | -0.85 | -0.69 | -0.89 | 0.06 |
| 1258.92 | | | -0.79 | -0.23 | 0.12 |
| 1584.89 | | | -1.02 | -0.06 | -0.21 |
| 1995.25 | | | -1.33 | -0.40 | -0.33 |
| 2511.88 | | | -1.76 | -0.19 | -0.01 |
| 3162.27 | | | -2.40 | -0.26 | -0.16 |
| 3981.05 | | | -3.25 | -0.40 | -0.15 |
| 5011.86 | | | -4.37 | -0.74 | -0.26 |
| 6309.54 | | | | -1.16 | -0.05 |
| 7943.25 | | | | -1.51 | -0.27 |
| 9999.96 | | | | -1.66 | -0.25 |

## TABLE 6
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.24350E+02
YSC=  0.10000E+01
YRE=  0.91320E+01
H   =  0.60830E+01
B2  =  0.50000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.15000E+02
RM  =  0.17500E+00
G   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 0.73 | 2.90 | 6.41 | 11.03 | 16.35 |
| 12.59 | 0.51 | 2.34 | 5.62 | 10.09 | 15.33 |
| 15.85 | 0.10 | 1.43 | 4.39 | 8.66 | 13.81 |
| 19.95 | -0.33 | 0.41 | 3.04 | 7.11 | 12.15 |
| 25.12 | -0.63 | -0.60 | 1.67 | 5.51 | 10.45 |
| 31.62 | -0.58 | -1.49 | 0.37 | 3.94 | 8.76 |
| 39.81 | -0.04 | -2.11 | -0.81 | 2.43 | 7.12 |
| 50.12 | 0.68 | -2.26 | -1.81 | 1.02 | 5.53 |
| 63.10 | 0.31 | -1.59 | -2.56 | -0.27 | 4.01 |
| 79.43 | -0.67 | 0.40 | -2.94 | -1.42 | 2.57 |
| 100.00 | 0.28 | 2.52 | -2.76 | -2.37 | 1.21 |
| 125.89 | -0.16 | -0.11 | -1.62 | -3.05 | -0.06 |
| 158.49 | 0.19 | -1.94 | 0.96 | -3.34 | -1.22 |
| 199.53 | -0.36 | 1.47 | 2.77 | -3.01 | -2.24 |
| 251.19 | -0.17 | -1.56 | -0.55 | -1.67 | -3.06 |
| 316.23 | -0.15 | 0.46 | -1.74 | 1.10 | -3.55 |
| 398.11 | -0.46 | -1.14 | 1.50 | 2.63 | -3.49 |
| 501.19 | -0.54 | -1.47 | -1.41 | -0.44 | -2.51 |
| 630.95 | -0.95 | -2.12 | 0.40 | -1.34 | 0.06 |
| 794.33 | -1.29 | -2.77 | -0.46 | 0.91 | 3.34 |
| 1000.00 | -1.90 | -3.76 | -0.82 | -0.50 | 0.50 |
| 1258.92 | | | -1.17 | 0.22 | -2.05 |
| 1584.89 | | | -1.25 | -0.12 | 0.66 |
| 1995.25 | | | -1.89 | -0.04 | -0.51 |
| 2511.88 | | | -2.73 | -0.07 | 0.22 |
| 3162.27 | | | -3.79 | -0.24 | -0.53 |
| 3981.05 | | | | -0.11 | -0.19 |
| 5011.86 | | | | -0.16 | -0.14 |
| 6309.54 | | | | -0.42 | -0.24 |
| 7943.25 | | | | -0.40 | -0.18 |
| 9999.96 | | | | -0.89 | -0.29 |

## TABLE 7
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.21310E+02
YSC=  0.10000E+01
YRE=  0.60880E+01
H   =  0.91320E+01
B2  =  0.50000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.15000E+02
RM  =  0.17500E+00
Q   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 1.41 | 3.83 | 7.04 | 11.40 | 16.54 |
| 12.59 | 1.17 | 3.37 | 6.38 | 10.62 | 15.70 |
| 15.85 | 0.68 | 2.57 | 5.34 | 9.45 | 14.47 |
| 19.95 | 0.02 | 1.65 | 4.21 | 8.20 | 13.18 |
| 25.12 | -0.65 | 0.68 | 3.05 | 6.93 | 11.86 |
| 31.62 | -1.19 | -0.26 | 1.93 | 5.68 | 10.56 |
| 39.81 | -1.40 | -1.12 | 0.86 | 4.46 | 9.29 |
| 50.12 | -0.99 | -1.83 | -0.11 | 3.29 | 8.05 |
| 63.10 | 0.38 | -2.26 | -0.98 | 2.16 | 6.83 |
| 79.43 | 1.97 | -2.22 | -1.69 | 1.07 | 5.61 |
| 100.00 | 0.18 | -1.31 | -2.20 | 0.04 | 4.38 |
| 125.89 | -2.02 | 1.02 | -2.39 | -0.92 | 3.14 |
| 158.49 | 0.73 | 2.88 | -2.10 | -1.75 | 1.88 |
| 199.53 | -0.97 | -0.71 | -1.04 | -2.40 | 0.62 |
| 251.19 | -0.71 | -2.53 | 0.89 | -2.75 | -0.59 |
| 316.23 | -2.37 | 1.68 | 1.76 | -2.62 | -1.71 |
| 398.11 | -2.46 | -2.44 | -0.37 | -1.75 | -2.64 |
| 501.19 | -3.49 | -0.61 | -1.00 | 0.12 | -3.29 |
| 630.95 | | -3.01 | 0.80 | 1.97 | -3.47 |
| 794.33 | | -3.65 | -0.65 | 0.65 | -2.85 |
| 1000.00 | | -4.84 | 0.12 | -1.15 | -0.91 |
| 1258.92 | | | -0.10 | 0.03 | 2.52 |
| 1584.89 | | | -0.39 | 0.13 | 1.71 |
| 1995.25 | | | -0.60 | -0.12 | -1.74 |
| 2511.88 | | | -1.07 | -0.16 | -0.57 |
| 3162.27 | | | -1.56 | -0.03 | 0.49 |
| 3981.05 | | | -2.10 | -0.04 | -0.62 |
| 5011.86 | | | -2.95 | -0.05 | -0.44 |
| 6309.54 | | | | -0.06 | -0.20 |
| 7943.25 | | | | -0.06 | -0.27 |
| 9999.96 | | | | -0.07 | -0.24 |

## TABLE 8
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.18260E+02
YSC=   0.10000E+01
YRE=   0.30440E+01
H   =  0.12180E+02
H2  =  0.50000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.15000E+02
RM  =  0.17500E+00
G   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTANE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 2.29 | 4.34 | 7.39 | 11.72 | 16.86 |
| 12.59 | 2.17 | 4.04 | 6.94 | 11.21 | 16.33 |
| 15.85 | 1.80 | 3.49 | 6.24 | 10.46 | 15.56 |
| 19.95 | 1.21 | 2.82 | 5.48 | 9.67 | 14.77 |
| 25.12 | 0.47 | 2.11 | 4.68 | 8.86 | 13.97 |
| 31.62 | -0.35 | 1.38 | 3.88 | 8.04 | 13.16 |
| 39.81 | -1.16 | 0.67 | 3.08 | 7.21 | 12.34 |
| 50.12 | -1.88 | -0.03 | 2.29 | 6.36 | 11.48 |
| 63.10 | -2.38 | -0.70 | 1.51 | 5.46 | 10.56 |
| 79.43 | -2.46 | -1.30 | 0.75 | 4.52 | 9.55 |
| 100.00 | -1.56 | -1.78 | 0.03 | 3.54 | 8.46 |
| 125.89 | 0.95 | -2.01 | -0.61 | 2.53 | 7.28 |
| 158.49 | 4.61 | -1.79 | -1.16 | 1.51 | 6.04 |
| 199.53 | -0.85 | -0.75 | -1.56 | 0.52 | 4.77 |
| 251.19 | -4.84 | 1.42 | -1.72 | -0.42 | 3.49 |
| 316.23 | -3.18 | 2.32 | -1.55 | -1.25 | 2.24 |
| 398.11 | -4.28 | -1.07 | -0.94 | -1.92 | 1.02 |
| 501.19 | | -2.39 | 0.04 | -2.35 | -0.12 |
| 630.95 | | 0.65 | 0.71 | -2.42 | -1.17 |
| 794.33 | | -2.37 | 0.43 | -1.96 | -2.08 |
| 1000.00 | | -2.20 | -0.12 | -0.75 | -2.78 |
| 1258.92 | | | -0.37 | 1.00 | -3.15 |
| 1584.89 | | | 0.23 | 1.29 | -2.99 |
| 1995.25 | | | -0.18 | -0.44 | -1.93 |
| 2511.86 | | | -0.03 | -0.67 | 0.54 |
| 3162.27 | | | -0.11 | 0.30 | 2.43 |
| 3981.05 | | | -0.11 | -0.23 | -0.51 |
| 5011.86 | | | -0.17 | -0.08 | -1.59 |
| 6309.54 | | | -0.27 | -0.14 | 0.28 |
| 7943.25 | | | -0.46 | -0.06 | -0.69 |
| 9999.95 | | | -0.45 | -0.04 | -0.58 |

## TABLE 9
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.15220E+02
YSC =  0.10000E+01
YRE =  0.00000E+00
H   =  0.15220E+02
B2  =  0.50000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.15000E+02
RM  =  0.17500E+00
Q   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 2.42 | 4.09 | 7.40 | 11.99 | 17.28 |
| 12.59 | 2.50 | 3.99 | 7.25 | 11.83 | 17.12 |
| 15.85 | 2.46 | 3.78 | 7.01 | 11.60 | 16.91 |
| 19.95 | 2.28 | 3.51 | 6.75 | 11.38 | 16.72 |
| 25.12 | 2.01 | 3.20 | 6.47 | 11.15 | 16.53 |
| 31.62 | 1.66 | 2.86 | 6.14 | 10.88 | 16.30 |
| 39.81 | 1.25 | 2.50 | 5.77 | 10.54 | 16.00 |
| 50.12 | 0.76 | 2.14 | 5.34 | 10.12 | 15.59 |
| 63.10 | 0.20 | 1.78 | 4.86 | 9.59 | 15.04 |
| 79.43 | -0.43 | 1.44 | 4.35 | 8.97 | 14.37 |
| 100.00 | -1.12 | 1.11 | 3.81 | 8.28 | 13.59 |
| 125.89 | -1.88 | 0.78 | 3.27 | 7.54 | 12.74 |
| 158.49 | -2.71 | 0.44 | 2.75 | 6.77 | 11.86 |
| 199.53 | -3.58 | 0.11 | 2.25 | 6.00 | 10.97 |
| 251.19 | -4.44 | -0.21 | 1.78 | 5.25 | 10.08 |
| 316.23 | -5.18 | -0.48 | 1.36 | 4.52 | 9.20 |
| 398.11 | -5.57 | -0.66 | 0.98 | 3.82 | 8.33 |
| 501.19 | | -0.65 | 0.64 | 3.17 | 7.47 |
| 630.95 | | -0.36 | 0.34 | 2.56 | 6.65 |
| 794.33 | | 0.10 | 0.08 | 2.01 | 5.85 |
| 1000.00 | | 0.45 | -0.13 | 1.51 | 5.10 |
| 1258.92 | | -0.15 | -0.27 | 1.05 | 4.39 |
| 1584.89 | | -0.31 | -0.29 | 0.63 | 3.71 |
| 1995.25 | | -0.43 | -0.26 | 0.23 | 3.03 |
| 2511.88 | | -1.40 | -0.12 | -0.13 | 2.32 |
| 3162.27 | | -1.60 | 0.06 | -0.41 | 1.57 |
| 3981.05 | | -1.91 | 0.09 | -0.53 | 0.77 |
| 5011.86 | | -3.15 | -0.02 | -0.37 | -0.03 |
| 6309.54 | | | 0.07 | 0.02 | -0.72 |
| 7943.25 | | | 0.02 | 0.15 | -1.12 |
| 9999.96 | | | 0.09 | -0.10 | -1.11 |

## TABLE 10
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.27400E+02
YSC =  0.10000E+01
YRE =  0.00000E+00
H   =  0.30440E+01
BE  =  0.50000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.30000E+02
RM  =  0.22500E+00
Q   =  0.10000E+04
CK  =  0.10000E+06
R2  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 1.09 | 4.75 | 9.48 | 14.89 | 20.63 |
| 12.59 | 1.21 | 4.85 | 9.58 | 15.02 | 20.78 |
| 15.85 | 1.35 | 4.92 | 9.64 | 15.08 | 20.84 |
| 19.95 | 1.44 | 4.91 | 9.54 | 14.95 | 20.69 |
| 25.12 | 1.46 | 4.77 | 9.24 | 14.54 | 20.21 |
| 31.62 | 1.42 | 4.48 | 8.70 | 13.82 | 19.39 |
| 39.81 | 1.31 | 4.06 | 7.93 | 12.82 | 18.25 |
| 50.12 | 1.14 | 3.54 | 6.99 | 11.62 | 16.90 |
| 63.10 | 0.94 | 2.97 | 5.98 | 10.32 | 15.45 |
| 79.43 | 0.71 | 2.40 | 4.95 | 9.00 | 13.98 |
| 100.00 | 0.46 | 1.84 | 3.96 | 7.71 | 12.55 |
| 125.89 | 0.19 | 1.31 | 3.04 | 6.50 | 11.20 |
| 158.49 | -0.09 | 0.79 | 2.21 | 5.37 | 9.94 |
| 199.53 | -0.35 | 0.29 | 1.46 | 4.32 | 8.76 |
| 251.19 | -0.52 | -0.18 | 0.81 | 3.37 | 7.67 |
| 316.23 | -0.48 | -0.62 | 0.23 | 2.49 | 6.66 |
| 398.11 | -0.21 | -0.95 | -0.25 | 1.70 | 5.70 |
| 501.19 | -0.07 | -1.08 | -0.65 | 0.99 | 4.80 |
| 630.95 | -0.43 | -0.86 | -0.94 | 0.38 | 3.92 |
| 794.33 | -0.46 | -0.41 | -1.06 | -0.14 | 3.08 |
| 1000.00 | -0.47 | -0.48 | -0.94 | -0.53 | 2.28 |
| 1258.92 | | -1.13 | -0.55 | -0.76 | 1.52 |
| 1584.89 | | -0.97 | -0.17 | -0.79 | 0.82 |
| 1995.25 | | -1.58 | -0.30 | -0.63 | 0.19 |
| 2511.88 | | -1.77 | -0.45 | -0.33 | -0.36 |
| 3162.27 | | -2.28 | -0.24 | -0.04 | -0.76 |
| 3981.05 | | -5.42 | -0.48 | 0.13 | -0.92 |
| 5011.86 | | -5.17 | -0.68 | -0.05 | -0.75 |
| 6309.54 | | | -1.13 | -0.04 | -0.30 |
| 7943.25 | | | 0.75 | 0.07 | 0.12 |
| 9999.96 | | | -1.71 | -0.04 | 0.01 |

## TABLE 11
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.24350E+02
YSC =  0.10000E+01
YRE =  0.00000E+00
H   =  0.60880E+01
B2  =  0.50000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.30000E+02
RM  =  0.22500E+00
Q   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTANE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 1.63 | 5.05 | 9.41 | 14.51 | 20.05 |
| 12.59 | 1.78 | 5.11 | 9.36 | 14.39 | 19.90 |
| 15.85 | 1.[illegible]2 | 5.06 | 9.13 | 14.04 | 19.47 |
| 19.95 | 1.96 | 4.84 | 8.68 | 13.44 | 18.79 |
| 25.12 | 1.88 | 4.45 | 8.04 | 12.66 | 17.94 |
| 31.62 | 1.70 | 3.93 | 7.27 | 11.78 | 17.00 |
| 39.81 | 1.42 | 3.34 | 6.45 | 10.85 | 16.03 |
| 50.12 | 1.10 | 2.73 | 5.62 | 9.93 | 15.09 |
| 63.10 | 0.75 | 2.13 | 4.80 | 9.04 | 14.17 |
| 79.43 | 0.39 | 1.56 | 4.02 | 8.19 | 13.30 |
| 100.00 | 0.03 | 1.04 | 3.28 | 7.36 | 12.46 |
| 125.89 | -0.34 | 0.57 | 2.59 | 6.55 | 11.62 |
| 158.49 | -0.71 | 0.13 | 1.93 | 5.74 | 10.77 |
| 199.53 | -1.05 | -0.26 | 1.33 | 4.94 | 9.88 |
| 251.19 | -1.27 | -0.61 | 0.79 | 4.13 | 8.95 |
| 316.23 | -1.25 | -0.90 | 0.31 | 3.33 | 7.97 |
| 398.11 | -0.93 | -1.09 | -0.09 | 2.54 | 6.97 |
| 501.19 | -0.76 | -1.11 | -0.40 | 1.80 | 5.95 |
| 630.95 | -1.53 | -0.86 | -0.59 | 1.11 | 4.95 |
| 794.33 | -2.22 | -0.45 | -0.65 | 0.49 | 3.97 |
| 1000.00 | -2.34 | -0.48 | -0.55 | -0.02 | 3.03 |
| 1258.92 | | -1.13 | -0.31 | -0.41 | 2.14 |
| 1584.89 | | -1.11 | -0.07 | -0.66 | 1.33 |
| 1995.25 | | -1.55 | 0.03 | -0.73 | 0.60 |
| 2511.88 | | -2.03 | 0.07 | -0.59 | -0.04 |
| 3162.27 | | -3.10 | -0.01 | -0.27 | -0.55 |
| 3981.05 | | -5.00 | 0.06 | 0.06 | -0.88 |
| 5011.66 | | -3.44 | -0.05 | 0.07 | -0.94 |
| 6309.54 | | | -0.06 | -0.09 | -0.64 |
| 7943.25 | | | 0.35 | 0.08 | -0.09 |
| 9999.96 | | | -0.42 | 0.04 | 0.13 |

## TABLE 12
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.21310E+02
YSC=   0.10000E+01
YKE=   0.00000E+00
H   =  0.91320E+01
B2  =  0.50000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.30000E+02
RM  =  0.22500E+00
J   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTANE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 2.12 | 5.11 | 9.04 | 13.88 | 19.28 |
| 12.59 | 2.27 | 5.09 | 8.89 | 13.66 | 19.02 |
| 15.85 | 2.35 | 4.91 | 8.55 | 13.23 | 18.55 |
| 19.95 | 2.28 | 4.58 | 8.07 | 12.70 | 18.00 |
| 25.12 | 2.06 | 4.13 | 7.54 | 12.15 | 17.46 |
| 31.62 | 1.73 | 3.62 | 6.99 | 11.62 | 16.95 |
| 39.81 | 1.35 | 3.09 | 6.43 | 11.09 | 16.46 |
| 50.12 | 0.95 | 2.56 | 5.86 | 10.55 | 15.94 |
| 63.10 | 0.54 | 2.04 | 5.26 | 9.95 | 15.36 |
| 79.43 | 0.14 | 1.54 | 4.63 | 9.28 | 14.68 |
| 100.00 | -0.24 | 1.07 | 3.97 | 8.53 | 13.89 |
| 125.89 | -0.62 | 0.64 | 3.30 | 7.71 | 12.99 |
| 158.49 | -0.98 | 0.25 | 2.63 | 6.84 | 12.02 |
| 199.53 | -1.31 | -0.09 | 1.99 | 5.94 | 11.00 |
| 251.19 | -1.55 | -0.37 | 1.38 | 5.04 | 9.97 |
| 316.23 | -1.59 | -0.59 | 0.83 | 4.16 | 8.92 |
| 398.11 | -1.33 | -0.70 | 0.35 | 3.29 | 7.88 |
| 501.19 | -1.01 | -0.69 | -0.05 | 2.47 | 6.85 |
| 630.95 | -1.56 | -0.51 | -0.34 | 1.70 | 5.82 |
| 794.33 | -2.70 | -0.21 | -0.52 | 1.00 | 4.81 |
| 1000.00 | -2.91 | -0.05 | -0.57 | 0.38 | 3.83 |
| 1258.92 | | -0.26 | -0.48 | -0.12 | 2.89 |
| 1584.89 | | -0.24 | -0.28 | -0.50 | 2.01 |
| 1995.25 | | -0.16 | -0.05 | -0.71 | 1.19 |
| 2511.88 | | -0.30 | 0.06 | -0.73 | 0.45 |
| 3162.27 | | -0.49 | -0.03 | -0.52 | -0.18 |
| 3981.05 | | -0.53 | -0.00 | -0.15 | -0.69 |
| 5011.86 | | -0.51 | 0.06 | 0.12 | -0.99 |
| 6309.54 | | -2.07 | 0.03 | -0.01 | -0.96 |
| 7943.25 | | -2.49 | 0.05 | -0.07 | -0.51 |
| 9999.96 | | -1.49 | 0.32 | 0.14 | -0.05 |

TABLE 13
GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.18260E+02
YSC=   0.10000E+01
YRE=   0.00000E+00
H   =  0.12180E+02
B2  =  0.50000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.30000E+02
RM  =  0.22500E+00
Q   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTANE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 2.44 | 4.94 | 8.65 | 13.41 | 18.79 |
| 12.59 | 2.55 | 4.90 | 8.54 | 13.28 | 18.65 |
| 15.85 | 2.54 | 4.73 | 8.33 | 13.07 | 18.45 |
| 19.95 | 2.35 | 4.46 | 8.10 | 12.90 | 18.31 |
| 25.12 | 2.05 | 4.14 | 7.88 | 12.76 | 18.24 |
| 31.62 | 1.69 | 3.80 | 7.64 | 12.62 | 18.15 |
| 39.81 | 1.31 | 3.43 | 7.32 | 12.36 | 17.94 |
| 50.12 | 0.93 | 3.01 | 6.88 | 11.93 | 17.51 |
| 63.10 | 0.56 | 2.55 | 6.32 | 11.32 | 16.86 |
| 79.43 | 0.19 | 2.07 | 5.67 | 10.56 | 16.04 |
| 100.00 | -0.16 | 1.59 | 4.95 | 9.70 | 15.11 |
| 125.89 | -0.48 | 1.14 | 4.20 | 8.80 | 14.13 |
| 158.49 | -0.78 | 0.72 | 3.45 | 7.87 | 13.13 |
| 199.53 | -1.03 | 0.34 | 2.73 | 6.94 | 12.11 |
| 251.19 | -1.21 | 0.02 | 2.04 | 6.01 | 11.08 |
| 316.23 | -1.24 | -0.22 | 1.40 | 5.09 | 10.03 |
| 398.11 | -1.04 | -0.39 | 0.82 | 4.18 | 8.96 |
| 501.19 | -0.65 | -0.45 | 0.32 | 3.30 | 7.93 |
| 630.95 | -0.61 | -0.40 | -0.09 | 2.47 | 6.88 |
| 794.33 | -1.43 | -0.24 | -0.39 | 1.63 | 5.84 |
| 1000.00 | -1.84 | -0.07 | -0.57 | 0.97 | 4.81 |
| 1258.92 | | 0.00 | -0.60 | 0.35 | 3.82 |
| 1584.89 | | 0.03 | -0.47 | -0.16 | 2.88 |
| 1995.25 | | 0.02 | -0.23 | -0.54 | 1.98 |
| 2511.88 | | 0.02 | 0.01 | -0.75 | 1.14 |
| 3162.27 | | -0.00 | 0.06 | -0.74 | 0.38 |
| 3981.05 | | -0.02 | -0.04 | -0.48 | -0.30 |
| 5011.86 | | -0.12 | 0.04 | -0.05 | -0.84 |
| 6309.54 | | 0.17 | 0.03 | 0.13 | -1.12 |
| 7943.25 | | -0.13 | 0.08 | -0.11 | -0.99 |
| 9999.96 | | 0.02 | 0.01 | -0.11 | -0.59 |

## TABLE 14
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH HEAVY UNDERGROWTH

```
SY  =  0.15220E+02
YSC=  0.10000E+01
YRE=  0.00000E+00
H   =  0.15220E+02
B2  =  0.50000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.30000E+02
RM  =  0.22500E+00
Q   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.5$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 2.43 | 4.64 | 8.40 | 13.26 | 18.69 |
| 12.59 | 2.52 | 4.70 | 8.48 | 13.36 | 18.82 |
| 15.85 | 2.49 | 4.71 | 8.61 | 13.57 | 19.08 |
| 19.95 | 2.32 | 4.70 | 8.78 | 13.87 | 19.44 |
| 25.12 | 2.09 | 4.65 | 8.91 | 14.13 | 19.78 |
| 31.62 | 1.83 | 4.53 | 8.90 | 14.18 | 19.87 |
| 39.81 | 1.56 | 4.27 | 8.65 | 13.92 | 19.59 |
| 50.12 | 1.26 | 3.88 | 8.16 | 13.37 | 19.00 |
| 63.10 | 0.95 | 3.40 | 7.52 | 12.63 | 18.21 |
| 79.43 | 0.62 | 2.87 | 6.78 | 11.80 | 17.33 |
| 100.00 | 0.30 | 2.32 | 6.00 | 10.91 | 16.40 |
| 125.89 | 0.00 | 1.79 | 5.21 | 10.01 | 15.45 |
| 158.49 | -0.26 | 1.29 | 4.41 | 9.08 | 14.46 |
| 199.53 | -0.48 | 0.84 | 3.63 | 8.14 | 13.45 |
| 251.19 | -0.62 | 0.43 | 2.88 | 7.19 | 12.42 |
| 316.23 | -0.66 | 0.09 | 2.17 | 6.24 | 11.37 |
| 398.11 | -0.56 | -0.18 | 1.50 | 5.30 | 10.31 |
| 501.19 | -0.31 | -0.36 | 0.89 | 4.37 | 9.23 |
| 630.95 | -0.06 | -0.44 | 0.37 | 3.47 | 8.16 |
| 794.33 | -0.18 | -0.40 | -0.07 | 2.61 | 7.08 |
| 1000.00 | | -0.27 | -0.40 | 1.80 | 6.02 |
| 1258.92 | | -0.09 | -0.59 | 1.06 | 4.99 |
| 1584.89 | | 0.03 | -0.62 | 0.41 | 3.99 |
| 1995.25 | | 0.01 | -0.48 | -0.13 | 3.02 |
| 2511.88 | | -0.03 | -0.20 | -0.54 | 2.09 |
| 3162.27 | | 0.03 | 0.05 | -0.78 | 1.21 |
| 3981.05 | | 0.01 | 0.06 | -0.78 | 0.38 |
| 5011.86 | | 0.04 | -0.05 | -0.48 | -0.38 |
| 6309.54 | | 0.14 | 0.07 | -0.01 | -0.98 |
| 7943.25 | | 0.02 | 0.02 | 0.10 | -1.27 |
| 9999.96 | | 0.01 | 0.11 | -0.16 | -1.20 |

## TABLE 15
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH SPARSE UNDERGROWTH

```
SY  =  0.27400E+02
YSC=   0.10000E+01
YRE=   0.00000E+00
H   =  0.30440E+01
B2  =  0.20000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.20000E+02
RM  =  0.22500E+00
Q   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```



$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -1.95 | 0.54 | 3.88 | 8.14 | 13.15 |
| 12.59 | -1.80 | 0.76 | 4.24 | 8.62 | 13.69 |
| 15.85 | -1.63 | 1.02 | 4.65 | 9.17 | 14.33 |
| 19.95 | -1.49 | 1.20 | 4.97 | 9.62 | 14.87 |
| 25.12 | -1.38 | 1.30 | 5.17 | 9.95 | 15.29 |
| 31.62 | -1.30 | 1.32 | 5.22 | 10.12 | 15.55 |
| 39.81 | -1.24 | 1.27 | 5.10 | 10.07 | 15.59 |
| 50.12 | -1.17 | 1.16 | 4.81 | 9.77 | 15.32 |
| 63.10 | -1.09 | 1.02 | 4.38 | 9.19 | 14.70 |
| 79.43 | -0.97 | 0.87 | 3.85 | 8.38 | 13.75 |
| 100.00 | -0.79 | 0.71 | 3.26 | 7.39 | 12.55 |
| 125.89 | -0.52 | 0.54 | 2.67 | 6.33 | 11.22 |
| 158.49 | -0.15 | 0.39 | 2.10 | 5.26 | 9.85 |
| 199.53 | 0.25 | 0.24 | 1.56 | 4.23 | 8.52 |
| 251.19 | 0.51 | 0.10 | 1.06 | 3.27 | 7.26 |
| 316.23 | 0.32 | -0.02 | 0.59 | 2.39 | 6.09 |
| 398.11 | -0.31 | -0.12 | 0.15 | 1.61 | 5.03 |
| 501.19 | -0.71 | -0.17 | -0.24 | 0.93 | 4.06 |
| 630.95 | -0.43 | -0.14 | -0.58 | 0.33 | 3.20 |
| 794.33 | -0.96 | -0.03 | -0.80 | -0.17 | 2.43 |
| 1000.00 | -1.64 | 0.02 | -0.79 | -0.54 | 1.78 |
| 1258.92 | | -0.08 | -0.50 | -0.76 | 1.23 |
| 1584.89 | | -0.03 | -0.16 | -0.75 | 0.78 |
| 1995.26 | | -0.05 | -0.31 | -0.50 | 0.40 |
| 2511.88 | | -0.01 | -0.48 | -0.16 | -0.01 |
| 3162.27 | | 0.04 | -0.30 | 0.00 | -0.49 |
| 3981.05 | | -0.77 | -0.58 | 0.16 | -0.78 |
| 5011.86 | | -0.38 | -0.82 | -0.04 | -0.60 |
| 6309.54 | | -0.56 | -1.32 | -0.10 | -0.27 |
| 7943.25 | | -0.96 | 0.69 | 0.01 | 0.14 |
| 9999.96 | | -0.60 | -1.96 | -0.13 | 0.06 |

## TABLE 16
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH SPARSE UNDERGROWTH

```
SY  =  0.24350E+02
YSC =  0.10000E+01
YNE =  0.00000E+00
H   =  0.60880E+01
B2  =  0.20000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.20000E+02
RM  =  0.22500E+00
W   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

NOT REPRODUCIBLE

$\beta_2 = 0.2$

ONE-THIRD-OCTANE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -1.28 | 1.46 | 5.30 | 10.01 | 15.30 |
| 12.59 | -1.00 | 1.86 | 5.90 | 10.81 | 16.22 |
| 15.85 | -0.68 | 2.29 | 6.55 | 11.68 | 17.26 |
| 19.95 | -0.42 | 2.56 | 6.92 | 12.21 | 17.92 |
| 25.12 | -0.23 | 2.64 | 6.94 | 12.26 | 18.00 |
| 31.62 | -0.13 | 2.54 | 6.63 | 11.82 | 17.49 |
| 39.81 | -0.08 | 2.32 | 6.04 | 10.99 | 16.52 |
| 50.12 | -0.05 | 2.03 | 5.31 | 9.96 | 15.31 |
| 63.10 | -0.00 | 1.71 | 4.52 | 8.85 | 14.02 |
| 79.43 | 0.08 | 1.39 | 3.73 | 7.75 | 12.76 |
| 100.00 | 0.25 | 1.07 | 2.99 | 6.70 | 11.58 |
| 125.89 | 0.52 | 0.76 | 2.31 | 5.72 | 10.48 |
| 158.49 | 0.89 | 0.47 | 1.70 | 4.82 | 9.46 |
| 199.53 | 1.26 | 0.20 | 1.15 | 3.99 | 8.52 |
| 251.19 | 1.31 | -0.05 | 0.67 | 3.23 | 7.62 |
| 316.23 | 0.64 | -0.27 | 0.25 | 2.52 | 6.75 |
| 398.11 | -0.63 | -0.46 | -0.12 | 1.88 | 5.90 |
| 501.19 | -1.51 | -0.54 | -0.41 | 1.30 | 5.05 |
| 630.95 | -1.67 | -0.46 | -0.61 | 0.79 | 4.23 |
| 794.33 | -2.44 | -0.22 | -0.67 | 0.37 | 3.43 |
| 1000.00 | -4.33 | -0.14 | -0.54 | 0.03 | 2.67 |
| 1258.92 | | -0.42 | -0.24 | -0.22 | 1.96 |
| 1584.89 | | -0.41 | -0.01 | -0.39 | 1.31 |
| 1995.25 | | -0.50 | -0.04 | -0.50 | 0.72 |
| 2511.89 | | -0.68 | 0.11 | -0.46 | 0.19 |
| 3162.27 | | -1.15 | -0.02 | -0.20 | -0.30 |
| 3981.05 | | -2.36 | -0.03 | 0.07 | -0.65 |
| 5011.86 | | -0.28 | -0.34 | 0.09 | -0.79 |
| 6309.54 | | -1.89 | -0.58 | -0.05 | -0.57 |
| 7943.25 | | -2.01 | 0.15 | 0.07 | -0.06 |
| 9999.96 | | -5.22 | -1.67 | 0.06 | 0.16 |

## TABLE 17
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH SPARSE UNDERGROWTH

```
SY  =  0.21310E+02
YSC =  0.10000E+01
YRE =  0.00000E+00
H   =  0.91320E+01
B2  =  0.20000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.20000E+02
RM  =  0.22500E+00
G   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -0.50 | 2.58 | 7.00 | 12.24 | 17.87 |
| 12.59 | -0.07 | 3.13 | 7.78 | 13.25 | 19.05 |
| 15.85 | 0.42 | 3.66 | 8.41 | 14.02 | 19.93 |
| 19.95 | 0.79 | 3.86 | 8.45 | 13.93 | 19.76 |
| 25.12 | 1.00 | 3.75 | 7.98 | 13.18 | 18.82 |
| 31.62 | 1.07 | 3.41 | 7.21 | 12.12 | 17.59 |
| 39.81 | 1.05 | 2.96 | 6.34 | 11.01 | 16.34 |
| 50.12 | 0.99 | 2.49 | 5.47 | 9.94 | 15.18 |
| 63.10 | 0.92 | 2.02 | 4.64 | 8.95 | 14.13 |
| 79.43 | 0.88 | 1.58 | 3.87 | 8.03 | 13.16 |
| 100.00 | 0.92 | 1.17 | 3.17 | 7.17 | 12.25 |
| 125.89 | 1.05 | 0.79 | 2.52 | 6.35 | 11.38 |
| 158.49 | 1.27 | 0.44 | 1.93 | 5.56 | 10.50 |
| 199.53 | 1.51 | 0.11 | 1.40 | 4.78 | 9.61 |
| 251.19 | 1.54 | -0.18 | 0.93 | 4.02 | 8.70 |
| 316.23 | 1.00 | -0.42 | 0.51 | 3.29 | 7.77 |
| 398.11 | -0.16 | -0.60 | 0.17 | 2.59 | 6.84 |
| 501.19 | -1.30 | -0.68 | -0.11 | 1.94 | 5.93 |
| 630.95 | -1.59 | -0.58 | -0.30 | 1.35 | 5.04 |
| 794.33 | -1.65 | -0.30 | -0.38 | 0.83 | 4.19 |
| 1000.00 | -3.56 | -0.12 | -0.36 | 0.37 | 3.39 |
| 1258.92 | | -0.37 | -0.26 | -0.00 | 2.64 |
| 1584.89 | | -0.41 | -0.16 | -0.29 | 1.93 |
| 1995.25 | | -0.33 | -0.04 | -0.47 | 1.27 |
| 2511.88 | | -0.56 | 0.07 | -0.52 | 0.65 |
| 3162.27 | | -0.83 | -0.06 | -0.40 | 0.06 |
| 3981.05 | | -0.92 | 0.01 | -0.11 | -0.45 |
| 5011.86 | | -0.95 | 0.06 | 0.14 | -0.81 |
| 6309.54 | | -3.07 | -0.04 | 0.02 | -0.86 |
| 7943.25 | | -3.67 | 0.07 | -0.06 | -0.47 |
| 9999.96 | | -2.85 | -0.01 | 0.14 | -0.03 |

## TABLE 18
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH SPARSE UNDERGROWTH

```
SY  =  0.12200E+02
ZSC=  0.10000E+01
YRE=  0.00000E+00
H   =  0.12120E+02
B2  =  0.20000E+00 ,   .00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.20000E+02
RM  =  0.22500E+00
G   =  0.10000E+04
CK  =  0.10000E+06
R2  =  0.11800E+01
```

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 0.39 | 3.89 | 8.95 | 14.74 | 20.74 |
| 12.59 | 1.00 | 4.54 | 9.69 | 15.56 | 21.63 |
| 15.85 | 1.64 | 4.97 | 9.85 | 15.47 | 21.34 |
| 19.95 | 2.03 | 4.83 | 9.28 | 14.50 | 20.12 |
| 25.12 | 2.15 | 4.47 | 8.41 | 13.35 | 18.82 |
| 31.62 | 2.09 | 3.93 | 7.51 | 12.30 | 17.69 |
| 39.81 | 1.91 | 3.30 | 6.66 | 11.36 | 16.73 |
| 50.12 | 1.66 | 2.73 | 5.88 | 10.52 | 15.88 |
| 63.10 | 1.44 | 2.21 | 5.15 | 9.73 | 15.07 |
| 79.43 | 1.21 | 1.73 | 4.45 | 8.95 | 14.28 |
| 100.00 | 1.04 | 1.30 | 3.79 | 8.17 | 13.45 |
| 125.89 | 0.93 | 0.91 | 3.15 | 7.38 | 12.58 |
| 158.49 | 0.58 | 0.55 | 2.55 | 6.56 | 11.66 |
| 199.53 | 0.68 | 0.22 | 1.98 | 5.75 | 10.73 |
| 251.19 | 0.34 | -0.07 | 1.46 | 4.94 | 9.78 |
| 316.23 | 0.66 | -0.30 | 1.00 | 4.15 | 8.82 |
| 398.11 | 0.22 | -0.45 | 0.59 | 3.39 | 7.88 |
| 501.19 | -0.35 | -0.51 | 0.24 | 2.67 | 6.95 |
| 630.95 | -0.55 | -0.43 | -0.04 | 2.01 | 6.04 |
| 794.33 | -0.59 | -0.21 | -0.25 | 1.40 | 5.16 |
| 1000.00 | -0.58 | -0.00 | -0.37 | 0.86 | 4.30 |
| 1258.92 | | -0.04 | -0.40 | 0.40 | 3.49 |
| 1584.89 | | -0.02 | -0.34 | 0.01 | 2.73 |
| 1995.26 | | 0.10 | -0.16 | -0.30 | 2.00 |
| 2511.88 | | -0.05 | 0.03 | -0.50 | 1.30 |
| 3162.27 | | -0.16 | 0.08 | -0.55 | 0.61 |
| 3981.06 | | -0.40 | -0.02 | -0.38 | -0.06 |
| 5011.86 | | -1.02 | 0.04 | -0.03 | -0.63 |
| 6309.54 | | -0.08 | 0.04 | 0.16 | -0.97 |
| 7943.25 | | -1.37 | 0.07 | -0.07 | -0.92 |
| 9999.96 | | -1.20 | -0.00 | -0.10 | -0.56 |

## TABLE 19
## GROUND ABSORPTION SPECTRUM FOR TREE STANDS WITH SPARSE UNDERGROWTH

```
SY  =  0.15220E+02
YSC =  0.10000E+01
YRE =  0.00000E+00
H   =  0.15220E+02
B2  =  0.20000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.20000E+02
RM  =  0.22500E+03
G   =  0.10000E+04
CK  =  0.10000E+05
R2  =  0.11600E+01
```

NOT REPRODUCIBLE

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | 1.36 | 5.35 | 10.94 | 17.09 | 23.32 |
| 12.59 | 2.12 | 5.90 | 11.18 | 17.01 | 22.99 |
| 15.85 | 2.79 | 5.95 | 10.56 | 15.86 | 21.50 |
| 19.95 | 3.01 | 5.48 | 9.61 | 14.63 | 20.13 |
| 25.12 | 2.89 | 4.85 | 8.73 | 13.66 | 19.13 |
| 31.62 | 2.61 | 4.22 | 7.99 | 12.91 | 18.39 |
| 39.81 | 2.26 | 3.63 | 7.32 | 12.25 | 17.75 |
| 50.12 | 1.90 | 3.07 | 6.66 | 11.60 | 17.11 |
| 63.10 | 1.54 | 2.56 | 6.03 | 10.91 | 16.41 |
| 79.43 | 1.19 | 2.09 | 5.38 | 10.17 | 15.62 |
| 100.00 | 0.86 | 1.66 | 4.71 | 9.35 | 14.77 |
| 125.89 | 0.57 | 1.27 | 4.04 | 8.55 | 13.87 |
| 158.49 | 0.32 | 0.91 | 3.39 | 7.71 | 12.94 |
| 199.53 | 0.14 | 0.57 | 2.76 | 6.87 | 12.00 |
| 251.19 | -0.01 | 0.27 | 2.17 | 6.03 | 11.05 |
| 316.23 | -0.14 | 0.02 | 1.62 | 5.20 | 10.10 |
| 398.11 | -0.24 | -0.15 | 1.13 | 4.40 | 9.14 |
| 501.19 | -0.26 | -0.29 | 0.69 | 3.62 | 8.19 |
| 630.96 | -0.22 | -0.31 | 0.31 | 2.89 | 7.25 |
| 794.33 | -0.03 | -0.23 | -0.00 | 2.21 | 6.33 |
| 1000.00 | 0.02 | -0.12 | -0.24 | 1.55 | 5.44 |
| 1258.92 | | -0.05 | -0.38 | 1.02 | 4.59 |
| 1584.89 | | 0.03 | -0.42 | 0.51 | 3.77 |
| 1995.26 | | 0.03 | -0.34 | 0.07 | 2.98 |
| 2511.88 | | -0.07 | -0.15 | -0.29 | 2.20 |
| 3162.27 | | 0.00 | 0.06 | -0.54 | 1.41 |
| 3981.05 | | 0.02 | 0.08 | -0.61 | 0.61 |
| 5011.86 | | -0.01 | -0.03 | -0.40 | -0.16 |
| 6309.54 | | 0.22 | 0.07 | 0.01 | -0.81 |
| 7943.25 | | -0.15 | 0.02 | 0.14 | -1.17 |
| 9999.96 | | -0.13 | 0.10 | -0.12 | -1.14 |

## TABLE 20
## GROUND ABSORPTION SPECTRUM FOR GRAIN CROPS AND TALL GRASSES

```
SY  =  0.12160E+01
YSC =  0.50000E+00
YRE =  0.12160E+01
H   =  0.15260E+01
SC  =  0.20000E+00 ,  0.00000E+00
SR  =  0.10000E+01
1   =  0.99600E+00
R1  =  0.20000E+02
RP  =  0.40000E+03
D   =  0.10000E+04
CK  =  0.10000E+06
R2  =  0.11800E+01
```

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -3.92 | 0.97 | 6.42 | 12.16 | 18.04 |
| 12.59 | -2.72 | 2.16 | 7.61 | 13.34 | 19.22 |
| 15.85 | -1.21 | 3.64 | 9.07 | 14.80 | 20.67 |
| 19.95 | 0.22 | 5.02 | 10.43 | 16.14 | 22.01 |
| 25.12 | 1.67 | 6.35 | 11.73 | 17.43 | 23.29 |
| 31.62 | 3.04 | 7.71 | 13.05 | 18.73 | 24.58 |
| 39.81 | 4.54 | 9.15 | 14.46 | 20.12 | 25.96 |
| 50.12 | 6.06 | 10.70 | 16.00 | 21.65 | 27.47 |
| 63.10 | 7.43 | 12.28 | 17.65 | 23.33 | 29.16 |
| 79.43 | 8.27 | 13.55 | 19.13 | 24.91 | 30.80 |
| 100.00 | 8.22 | 13.90 | 19.77 | 25.71 | 31.69 |
| 125.89 | 7.39 | 13.04 | 18.98 | 24.99 | 31.00 |
| 158.49 | 6.22 | 11.46 | 17.20 | 23.10 | 29.07 |
| 199.53 | 5.06 | 9.73 | 15.18 | 20.92 | 26.91 |
| 251.19 | 4.05 | 8.13 | 13.29 | 18.88 | 24.77 |
| 316.23 | 3.22 | 6.73 | 11.61 | 17.07 | 22.85 |
| 398.11 | 2.55 | 5.52 | 10.15 | 15.51 | 21.20 |
| 501.19 | 1.94 | 4.45 | 8.88 | 14.13 | 19.76 |
| 630.95 | 1.31 | 3.58 | 7.79 | 12.94 | 18.54 |
| 794.33 | 0.55 | 2.79 | 6.86 | 11.95 | 17.61 |
| 1000.00 | -0.33 | 2.10 | 6.09 | 11.15 | 16.79 |
| 1258.92 | -1.13 | 1.49 | 5.48 | 10.57 | 16.20 |
| 1584.89 | -1.73 | 1.00 | 5.06 | 10.21 | 15.85 |
| 1995.25 | -1.72 | 0.72 | 4.79 | 9.97 | 15.62 |
| 2511.88 | -0.55 | 0.66 | 4.46 | 9.43 | 14.93 |
| 3162.27 | 1.12 | 0.40 | 3.52 | 8.07 | 13.61 |
| 3981.05 | -0.86 | -0.91 | 1.83 | 6.30 | 11.79 |
| 5011.86 | -3.12 | -2.46 | 0.43 | 5.17 | 10.79 |
| 6309.54 | 1.18 | -2.29 | -0.33 | 3.95 | 9.13 |
| 7943.26 | -1.38 | -2.27 | -1.96 | 2.11 | 7.41 |
| 9999.96 | -2.51 | -2.36 | -2.58 | 1.17 | 6.18 |

## TABLE 21
## GROUND ABSORPTION SPECTRUM FOR GRAIN CROPS AND TALL GRASSES

```
SY  =  0.12180E+01
YSC=  0.50000E+00
YKE=  0.12180E+01
H   =  0.15200E+01
DZ  =  0.20000E+00 ,   0.30000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.40000E+02
RM  =  0.30000E+00
G   =  0.10000E+04
CK  =  0.10000E+06
R2  =  0.11800E+01
```

NOT REPRODUCIBLE

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -1.52 | 3.59 | 9.16 | 14.95 | 20.86 |
| 12.59 | -0.07 | 5.06 | 10.64 | 16.44 | 22.34 |
| 15.85 | 1.72 | 6.87 | 12.46 | 18.26 | 24.17 |
| 19.95 | 3.33 | 8.49 | 14.08 | 19.89 | 25.80 |
| 25.12 | 4.79 | 9.95 | 15.54 | 21.35 | 27.26 |
| 31.62 | 6.13 | 11.29 | 16.89 | 22.69 | 28.60 |
| 39.81 | 7.37 | 12.56 | 18.16 | 23.97 | 29.89 |
| 50.12 | 8.49 | 13.74 | 19.37 | 25.19 | 31.09 |
| 63.10 | 9.33 | 14.73 | 20.39 | 26.25 | 32.17 |
| 79.43 | 9.67 | 15.19 | 20.96 | 26.86 | 32.82 |
| 100.00 | 9.39 | 14.96 | 20.78 | 26.71 | 32.69 |
| 125.89 | 8.56 | 14.03 | 19.81 | 25.73 | 31.70 |
| 158.49 | 7.43 | 12.69 | 18.36 | 24.21 | 30.15 |
| 199.53 | 6.23 | 11.21 | 16.75 | 22.53 | 28.55 |
| 251.19 | 5.06 | 9.77 | 15.18 | 20.90 | 26.86 |
| 316.23 | 3.99 | 8.43 | 13.72 | 19.33 | 25.27 |
| 398.11 | 3.02 | 7.22 | 12.39 | 18.03 | 23.85 |
| 501.19 | 2.14 | 6.11 | 11.19 | 16.77 | 22.57 |
| 630.96 | 1.34 | 5.09 | 10.09 | 15.64 | 21.43 |
| 794.33 | 0.60 | 4.14 | 9.06 | 14.57 | 20.51 |
| 1000.00 | -0.06 | 3.24 | 8.07 | 13.56 | 19.45 |
| 1258.92 | -0.69 | 2.38 | 7.08 | 12.52 | 18.34 |
| 1584.89 | -1.18 | 1.54 | 6.06 | 11.43 | 17.15 |
| 1995.26 | -1.48 | 0.72 | 4.98 | 10.25 | 15.90 |
| 2511.88 | -1.51 | -0.10 | 3.82 | 8.91 | 14.50 |
| 3162.27 | -1.32 | -0.94 | 2.59 | 7.52 | 13.32 |
| 3981.05 | -1.13 | -1.74 | 1.36 | 6.16 | 11.84 |
| 5011.86 | -0.72 | -2.45 | 0.17 | 4.81 | 10.35 |
| 6309.54 | 1.22 | -2.67 | -0.98 | 3.39 | 8.72 |
| 7943.25 | 0.29 | -2.44 | -2.15 | 1.89 | 7.14 |
| 9999.96 | -0.48 | -1.71 | -2.89 | 0.76 | 5.89 |

# TABLE 22

## GROUND ABSORPTION SPECTRUM FOR GRAIN CROPS AND TALL GRASSES

```
SY  =  0.18260E+01
YSC =  0.50000E+00
YRE =  0.18260E+01
H   =  0.12150E+01
BE  =  0.20000E+00 ,  0.30000E+00
SR  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.20000E+02
RS  =  0.40000E+00
[illegible]   =  0.10000E+04
CR  =  0.10000E+06
RZ  =  0.11[illegible]E+01
```

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -3.31 | 0.86 | 6.05 | 11.66 | 17.47 |
| 12.59 | -2.43 | 1.92 | 7.10 | 12.71 | 18.52 |
| 15.85 | -1.08 | 3.21 | 8.37 | 13.96 | 19.76 |
| 19.95 | 0.19 | 4.39 | 9.50 | 15.03 | 20.87 |
| 25.12 | 1.43 | 5.51 | 10.57 | 16.11 | 21.89 |
| 31.62 | 2.71 | 6.65 | 11.63 | 17.14 | 22.90 |
| 39.81 | 4.05 | 7.86 | 12.76 | 18.22 | 23.96 |
| 50.12 | 5.41 | 9.18 | 14.01 | 19.43 | 25.13 |
| 63.10 | 6.61 | 10.58 | 15.40 | 20.80 | 26.49 |
| 79.43 | 7.32 | 11.88 | 16.87 | 22.31 | 28.02 |
| 100.00 | 7.22 | 12.56 | 18.04 | 23.69 | 29.50 |
| 125.89 | 6.44 | 12.18 | 18.16 | 24.15 | 30.14 |
| 158.49 | 5.36 | 10.79 | 16.86 | 22.99 | 29.08 |
| 199.53 | 4.25 | 8.99 | 14.75 | 20.75 | 26.88 |
| 251.19 | 3.34 | 7.20 | 12.53 | 18.29 | 24.28 |
| 316.23 | 2.50 | 5.56 | 10.44 | 15.97 | 21.80 |
| 398.11 | 1.56 | 4.11 | 8.57 | 13.90 | 19.58 |
| 501.19 | 0.70 | 2.81 | 6.88 | 12.00 | 17.58 |
| 630.96 | -0.42 | 1.64 | 5.36 | 10.20 | 15.77 |
| 794.33 | -1.58 | 0.55 | 3.99 | 8.74 | 14.24 |
| 1000.00 | -2.56 | -0.47 | 2.76 | 7.36 | 12.74 |
| 1258.92 | -3.08 | -1.42 | 1.65 | 6.13 | 11.43 |
| 1584.89 | -2.70 | -2.20 | 0.69 | 5.09 | 10.34 |
| 1995.25 | -0.63 | -2.62 | -0.07 | 4.28 | 9.53 |
| 2511.88 | 3.12 | -2.40 | -0.55 | 3.71 | 8.98 |
| 3162.27 | 0.19 | -1.28 | -0.77 | 3.23 | 8.61 |
| 3981.05 | -2.53 | -0.14 | -1.17 | 2.25 | 7.33 |
| 5011.86 | 1.14 | -0.77 | -2.46 | 0.24 | 4.97 |
| 6309.54 | -2.47 | 0.55 | -3.75 | -1.66 | 2.96 |
| 7943.25 | -1.24 | 1.16 | -2.87 | -2.41 | 1.92 |
| 9999.96 | -3.36 | -2.64 | -1.19 | -3.17 | 0.47 |

## TABLE 23
## GROUND ABSORPTION SPECTRUM FOR GRAIN CROPS AND TALL GRASSES

```
ST  =  0.18200E+01
YSC =  0.50000E+00
YRE =  0.12260E+01
H   =  0.12180E+01
S2  =  0.20000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.30000E+02
RM  =  0.60000E+00
W   =  0.10000E+04
CK  =  0.10000E+05
RZ  =  0.11800E+01
```

NOT REPRODUCIBLE

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -2.33 | 2.26 | 7.57 | 13.23 | 19.07 |
| 12.59 | -1.18 | 3.42 | 8.73 | 14.40 | 20.24 |
| 15.85 | 0.22 | 4.81 | 10.12 | 15.78 | 21.62 |
| 19.95 | 1.47 | 6.03 | 11.32 | 16.97 | 22.81 |
| 25.12 | 2.62 | 7.12 | 12.38 | 18.02 | 23.85 |
| 31.62 | 3.72 | 8.14 | 13.36 | 18.99 | 24.81 |
| 39.81 | 4.79 | 9.15 | 14.34 | 19.94 | 25.75 |
| 50.12 | 5.83 | 10.18 | 15.33 | 20.91 | 26.71 |
| 63.10 | 6.73 | 11.17 | 16.34 | 21.93 | 27.72 |
| 79.43 | 7.28 | 11.99 | 17.26 | 22.88 | 28.70 |
| 100.00 | 7.27 | 12.33 | 17.80 | 23.53 | 29.39 |
| 125.89 | 6.65 | 11.91 | 17.58 | 23.43 | 29.37 |
| 158.49 | 5.62 | 10.76 | 16.47 | 22.37 | 28.33 |
| 199.53 | 4.44 | 9.20 | 14.76 | 20.59 | 26.61 |
| 251.19 | 3.28 | 7.51 | 12.84 | 18.55 | 24.50 |
| 316.23 | 2.20 | 5.88 | 10.93 | 16.51 | 22.36 |
| 398.11 | 1.21 | 4.36 | 9.14 | 14.60 | 20.34 |
| 501.19 | 0.27 | 2.98 | 7.48 | 12.80 | 18.48 |
| 630.96 | -0.65 | 1.72 | 5.95 | 11.14 | 16.76 |
| 794.33 | -1.55 | 0.58 | 4.55 | 9.62 | 15.29 |
| 1000.00 | -2.31 | -0.44 | 3.28 | 8.22 | 13.80 |
| 1258.92 | -2.71 | -1.33 | 2.12 | 6.95 | 12.46 |
| 1584.89 | -2.38 | -2.04 | 1.09 | 5.81 | 11.24 |
| 1995.26 | -0.72 | -2.46 | 0.21 | 4.79 | 10.18 |
| 2511.88 | 2.16 | -2.44 | -0.54 | 3.83 | 9.16 |
| 3162.27 | 0.76 | -1.83 | -1.19 | 2.82 | 8.20 |
| 3981.05 | -1.63 | -0.90 | -1.91 | 1.55 | 6.68 |
| 5011.86 | 0.74 | -0.31 | -2.87 | -0.03 | 4.76 |
| 6309.54 | -1.22 | 1.29 | -3.57 | -1.59 | 3.03 |
| 7943.25 | -0.12 | 0.86 | -2.89 | -2.61 | 1.65 |
| 9999.96 | -2.21 | -1.97 | -1.51 | -3.41 | 0.32 |

## TABLE 24
## GROUND ABSORPTION SPECTRUM FOR DENSE, SHORT GRASSES

```
SY  =  0.91320E+00
YSC=   0.25000E+00
YRE=   0.91320E+00
H   =  0.60880E+00
B2  =  0.20000E+00 ,  0.00000E+00
SR  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.30000E+02
RM  =  0.40000E+00
[illegible]   =  0.10000E+04
CR  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -4.49 | 0.70 | 6.30 | 12.11 | 18.03 |
| 12.59 | -3.22 | 1.97 | 7.57 | 13.38 | 19.30 |
| 15.85 | -1.66 | 3.53 | 9.13 | 14.94 | 20.86 |
| 19.95 | -0.25 | 4.92 | 10.51 | 16.32 | 22.24 |
| 25.12 | 1.01 | 6.14 | 11.72 | 17.52 | 23.44 |
| 31.62 | 2.16 | 7.24 | 12.80 | 18.59 | 24.49 |
| 39.81 | 3.27 | 8.28 | 13.80 | 19.57 | 25.47 |
| 50.12 | 4.41 | 9.32 | 14.79 | 20.54 | 26.40 |
| 63.10 | 5.65 | 10.43 | 15.84 | 21.56 | 27.41 |
| 79.43 | 7.05 | 11.69 | 17.03 | 22.71 | 28.54 |
| 100.00 | 8.67 | 13.17 | 18.42 | 24.05 | 29.88 |
| 125.89 | 10.52 | 14.94 | 20.13 | 25.71 | 31.52 |
| 158.49 | 12.36 | 17.03 | 22.22 | 27.80 | 33.60 |
| 199.53 | 13.40 | 19.02 | 24.56 | 30.27 | 35.95 |
| 251.19 | 12.75 | 19.49 | 25.65 | 32.00 | 38.10 |
| 316.23 | 10.69 | 17.62 | 24.26 | 30.66 | 37.07 |
| 398.11 | 8.51 | 14.89 | 21.14 | 27.48 | 33.61 |
| 501.19 | 6.94 | 12.31 | 18.15 | 24.19 | 30.17 |
| 630.95 | 5.36 | 10.08 | 15.57 | 21.39 | 27.28 |
| 794.33 | 4.01 | 8.16 | 13.37 | 18.99 | 25.21 |
| 1000.00 | 2.82 | 6.49 | 11.42 | 16.90 | 22.94 |
| 1258.92 | 1.72 | 5.00 | 9.69 | 15.04 | 20.91 |
| 1584.89 | 0.64 | 3.67 | 8.14 | 13.47 | 19.12 |
| 1995.26 | -0.47 | 2.46 | 6.77 | 11.99 | 17.57 |
| 2511.88 | -1.53 | 1.36 | 5.57 | 10.70 | 16.26 |
| 3162.27 | -2.40 | 0.40 | 4.58 | 9.68 | 15.62 |
| 3981.05 | -2.34 | -0.32 | 3.88 | 9.03 | 14.97 |
| 5011.86 | -2.47 | -0.66 | 3.56 | 8.82 | 14.73 |
| 6309.54 | -0.93 | -0.52 | 3.55 | 8.98 | 14.79 |
| 7943.28 | 0.45 | -0.56 | 2.89 | 7.97 | 13.47 |
| 9999.96 | -0.69 | -1.58 | 1.22 | 5.93 | 11.25 |

## TABLE 25
## GROUND ABSORPTION SPECTRUM FOR DENSE, SHORT GRASSES

```
SY  =  0.91320E+00
YSC=   0.25000E+00
YRE=   0.91320E+00
H   =  0.60800E+00
B2  =  0.20000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.90000E+02
RM  =  0.12000E+01
G   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```



$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -2.26 | 3.07 | 8.75 | 14.60 | 20.53 |
| 12.59 | -0.61 | 4.75 | 10.43 | 16.29 | 22.22 |
| 15.85 | 1.51 | 6.91 | 12.61 | 18.47 | 24.41 |
| 19.95 | 3.48 | 8.93 | 14.62 | 20.49 | 26.43 |
| 25.12 | 5.21 | 10.66 | 16.39 | 22.26 | 28.21 |
| 31.62 | 6.69 | 12.15 | 17.88 | 23.76 | 29.71 |
| 39.81 | 7.93 | 13.38 | 19.12 | 25.00 | 30.95 |
| 50.12 | 8.98 | 14.42 | 20.16 | 26.03 | 31.96 |
| 63.10 | 9.91 | 15.34 | 21.06 | 26.93 | 32.86 |
| 79.43 | 10.77 | 16.17 | 21.89 | 27.75 | 33.68 |
| 100.00 | 11.57 | 16.97 | 22.67 | 28.53 | 34.47 |
| 125.89 | 12.27 | 17.69 | 23.40 | 29.27 | 35.21 |
| 158.49 | 12.73 | 18.22 | 23.96 | 29.85 | 35.80 |
| 199.53 | 12.75 | 18.33 | 24.14 | 30.05 | 36.10 |
| 251.19 | 12.16 | 17.82 | 23.67 | 29.61 | 35.74 |
| 316.23 | 11.01 | 16.66 | 22.51 | 28.45 | 34.57 |
| 398.11 | 9.52 | 15.06 | 20.86 | 26.88 | 32.86 |
| 501.19 | 7.89 | 13.27 | 19.00 | 24.95 | 30.90 |
| 630.95 | 6.27 | 11.45 | 17.12 | 23.00 | 28.92 |
| 794.33 | 4.73 | 9.75 | 15.32 | 21.11 | 27.52 |
| 1000.00 | 3.29 | 8.12 | 13.60 | 19.36 | 25.61 |
| 1258.92 | 1.97 | 6.60 | 11.99 | 17.70 | 23.82 |
| 1584.89 | 0.76 | 5.18 | 10.48 | 16.27 | 22.15 |
| 1995.26 | -0.32 | 3.86 | 9.06 | 14.79 | 20.63 |
| 2511.88 | -1.26 | 2.62 | 7.72 | 13.37 | 19.19 |
| 3162.27 | -2.01 | 1.46 | 6.43 | 12.00 | 18.41 |
| 3981.05 | -2.53 | 0.38 | 5.18 | 10.68 | 17.01 |
| 5011.86 | -2.69 | -0.64 | 3.89 | 9.30 | 15.40 |
| 6309.54 | -2.39 | -1.59 | 2.54 | 7.99 | 13.76 |
| 7943.25 | -1.50 | -2.49 | 1.12 | 6.34 | 11.97 |
| 9999.96 | -0.47 | -3.10 | 0.01 | 5.06 | 10.64 |

# TABLE 26
## GROUND ABSORPTION SPECTRUM FOR DENSE, SHORT GRASSES

```
SY  =  0.12180E+01
YSC =  0.25000E+00
YRE =  0.12180E+01
H   =  0.30440E+00
B2  =  0.20000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.90000E+02
RM  =  0.12000E+01
Q   =  0.10000E+04
CK  =  0.10000E+06
R2  =  0.11800E+01
```

$\beta_2 = 0.2$

ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -2.25 | 2.87 | 8.44 | 14.24 | 20.14 |
| 12.59 | -0.74 | 4.42 | 10.00 | 15.80 | 21.71 |
| 15.85 | 1.17 | 6.37 | 11.98 | 17.79 | 23.71 |
| 19.95 | 2.89 | 8.13 | 13.75 | 19.58 | 25.50 |
| 25.12 | 4.35 | 9.61 | 15.26 | 21.09 | 27.01 |
| 31.62 | 5.54 | 10.81 | 16.46 | 22.29 | 28.22 |
| 39.81 | 6.48 | 11.74 | 17.39 | 23.22 | 29.15 |
| 50.12 | 7.23 | 12.46 | 18.09 | 23.92 | 29.83 |
| 63.10 | 7.84 | 13.04 | 18.65 | 24.46 | 30.37 |
| 79.43 | 8.39 | 13.53 | 19.11 | 24.91 | 30.82 |
| 100.00 | 8.90 | 13.98 | 19.53 | 25.31 | 31.22 |
| 125.89 | 9.39 | 14.41 | 19.93 | 25.70 | 31.60 |
| 158.49 | 9.81 | 14.81 | 20.31 | 26.07 | 31.96 |
| 199.53 | 10.05 | 15.09 | 20.60 | 26.36 | 32.29 |
| 251.19 | 9.93 | 15.10 | 20.66 | 26.43 | 32.42 |
| 316.23 | 9.30 | 14.64 | 20.28 | 26.11 | 32.12 |
| 398.11 | 8.12 | 13.59 | 19.32 | 25.28 | 31.24 |
| 501.19 | 6.56 | 12.03 | 17.80 | 23.76 | 29.72 |
| 630.95 | 4.83 | 10.16 | 15.91 | 21.84 | 27.80 |
| 794.33 | 3.07 | 8.18 | 13.86 | 19.73 | 26.11 |
| 1000.00 | 1.40 | 6.21 | 11.77 | 17.59 | 23.83 |
| 1258.92 | -0.14 | 4.31 | 9.73 | 15.48 | 21.57 |
| 1584.89 | -1.50 | 2.53 | 7.76 | 13.52 | 19.40 |
| 1995.26 | -2.62 | 0.88 | 5.89 | 11.56 | 17.38 |
| 2511.88 | -3.41 | -0.62 | 4.13 | 9.65 | 15.43 |
| 3162.27 | -3.73 | -1.93 | 2.49 | 7.86 | 13.94 |
| 3981.05 | -3.25 | -2.99 | 0.99 | 6.20 | 12.19 |
| 5011.86 | -1.36 | -3.69 | -0.37 | 4.64 | 10.43 |
| 6309.54 | 2.49 | -3.87 | -1.53 | 3.25 | 8.80 |
| 7943.25 | 1.87 | -3.25 | -2.46 | 1.95 | 7.36 |
| 9999.96 | -1.37 | -2.06 | -3.00 | 1.01 | 6.31 |

## TABLE 27
## GROUND ABSORPTION SPECTRUM FOR DENSE, SHORT GRASSES

```
SY  =  0.12180E+01
YSC =  0.25000E+00
YRE =  0.12180E+01
H   =  0.30440E+00
B2  =  0.20000E+00 ,  0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.30000E+02
RM  =  0.40000E+00
G   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.2$



ONE-THIRD-OCTANE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -4.24 | 0.69 | 6.16 | 11.91 | 17.79 |
| 12.59 | -3.05 | 1.88 | 7.36 | 13.11 | 18.99 |
| 15.85 | -1.59 | 3.33 | 8.80 | 14.55 | 20.43 |
| 19.95 | -0.31 | 4.59 | 10.05 | 15.79 | 21.67 |
| 25.12 | 0.82 | 5.67 | 11.11 | 16.84 | 22.71 |
| 31.62 | 1.84 | 6.61 | 12.02 | 17.73 | 23.60 |
| 39.81 | 2.82 | 7.48 | 12.84 | 18.52 | 24.38 |
| 50.12 | 3.83 | 8.34 | 13.62 | 19.28 | 25.10 |
| 63.10 | 4.93 | 9.25 | 14.44 | 20.05 | 25.86 |
| 79.43 | 6.20 | 10.28 | 15.35 | 20.91 | 26.69 |
| 100.00 | 7.69 | 11.49 | 16.42 | 21.89 | 27.64 |
| 125.89 | 9.43 | 12.97 | 17.72 | 23.11 | 28.82 |
| 158.49 | 11.27 | 14.81 | 19.37 | 24.65 | 30.30 |
| 199.53 | 12.56 | 17.01 | 21.51 | 26.69 | 32.10 |
| 251.19 | 12.23 | 18.92 | 24.13 | 29.37 | 34.79 |
| 316.23 | 10.43 | 18.60 | 25.81 | 32.07 | 38.02 |
| 398.11 | 8.24 | 15.91 | 23.77 | 31.24 | 38.00 |
| 501.19 | 6.23 | 12.81 | 19.97 | 26.99 | 33.53 |
| 630.95 | 4.50 | 10.07 | 16.52 | 23.03 | 29.31 |
| 794.33 | 2.99 | 7.70 | 13.62 | 19.74 | 26.31 |
| 1000.00 | 1.60 | 5.64 | 11.09 | 16.94 | 23.22 |
| 1258.92 | 0.27 | 3.81 | 8.85 | 14.48 | 20.51 |
| 1584.89 | -1.06 | 2.15 | 6.82 | 12.32 | 18.08 |
| 1995.25 | -2.33 | 0.60 | 4.96 | 10.27 | 15.91 |
| 2511.88 | -3.36 | -0.86 | 3.23 | 8.34 | 13.89 |
| 3162.27 | -3.99 | -2.18 | 1.63 | 6.56 | 12.36 |
| 3981.05 | -3.75 | -3.30 | 0.18 | 4.96 | 10.66 |
| 5011.86 | -1.83 | -4.03 | -1.09 | 3.52 | 9.04 |
| 6309.54 | 3.16 | -4.07 | -2.04 | 2.39 | 7.72 |
| 7943.25 | 1.67 | -2.89 | -2.50 | 1.53 | 6.81 |
| 9999.96 | -2.41 | -0.83 | -2.47 | 1.22 | 6.38 |

## TABLE 28
## GROUND ABSORPTION SPECTRUM FOR DENSE, SHORT GRASSES

```
SY  =  0.13700E+01
YSC=   0.25000E+00
YRE=   0.13700E+01
H   =  0.15220E+00
DZ  =  0.20000E+00 ,   0.00000E+00
SR  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.60000E+02
RM  =  0.80000E+00
G   =  0.10000E+04
CR  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.2$



ONE-THIRD-OCTAVE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250. | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -2.62 | 2.37 | 7.87 | 13.62 | 19.51 |
| 12.59 | -1.31 | 3.70 | 9.21 | 14.98 | 20.87 |
| 15.85 | 0.30 | 5.34 | 10.87 | 16.64 | 22.54 |
| 19.95 | 1.69 | 6.75 | 12.29 | 18.07 | 23.96 |
| 25.12 | 2.85 | 7.90 | 13.44 | 19.22 | 25.12 |
| 31.62 | 3.78 | 8.81 | 14.34 | 20.12 | 26.02 |
| 39.81 | 4.54 | 9.53 | 15.04 | 20.80 | 26.70 |
| 50.12 | 5.19 | 10.10 | 15.58 | 21.33 | 27.20 |
| 63.10 | 5.79 | 10.60 | 16.03 | 21.76 | 27.62 |
| 79.43 | 6.40 | 11.09 | 16.45 | 22.15 | 28.01 |
| 100.00 | 7.06 | 11.60 | 16.89 | 22.55 | 28.39 |
| 125.89 | 7.78 | 12.17 | 17.38 | 22.99 | 28.81 |
| 158.49 | 8.54 | 12.81 | 17.93 | 23.50 | 29.29 |
| 199.53 | 9.23 | 13.49 | 18.54 | 24.07 | 29.83 |
| 251.19 | 9.59 | 14.10 | 19.16 | 24.67 | 30.43 |
| 316.23 | 9.28 | 14.36 | 19.60 | 25.16 | 30.95 |
| 398.11 | 8.16 | 13.90 | 19.51 | 25.28 | 31.12 |
| 501.19 | 6.46 | 12.54 | 18.55 | 24.57 | 30.53 |
| 630.95 | 4.54 | 10.54 | 16.74 | 22.91 | 28.98 |
| 794.33 | 2.64 | 8.28 | 14.47 | 20.65 | 27.23 |
| 1000.00 | 0.87 | 6.03 | 12.05 | 18.18 | 24.60 |
| 1258.92 | -0.73 | 3.87 | 9.66 | 15.69 | 21.94 |
| 1584.89 | -2.13 | 1.87 | 7.37 | 13.38 | 19.40 |
| 1995.25 | -3.26 | 0.03 | 5.20 | 11.04 | 16.98 |
| 2511.85 | -4.30 | -1.63 | 3.15 | 8.81 | 14.69 |
| 3162.27 | -4.07 | -3.06 | 1.25 | 6.68 | 12.94 |
| 3981.05 | -2.85 | -4.17 | -0.51 | 4.70 | 10.72 |
| 5011.86 | 1.08 | -4.82 | -2.09 | 2.80 | 8.61 |
| 6309.54 | 4.22 | -4.65 | -3.43 | 1.11 | 6.57 |
| 7943.25 | -2.07 | -2.91 | -4.40 | -0.46 | 4.79 |
| 9999.96 | -3.32 | 0.41 | -4.79 | -1.55 | 3.52 |

## TABLE 29
## GROUND ABSORPTION SPECTRUM FOR DENSE, SHORT GRASSES

```
SY  =  0.13700E+01
YSC=   0.25000E+00
YRE=   0.13700E+01
H   =  0.15220E+00
B2  =  0.20000E+00 ,   0.00000E+00
SK  =  0.10000E+01
Y   =  0.99600E+00
R1  =  0.90000E+02
RM  =  0.12000E+01
G   =  0.10000E+04
CK  =  0.10000E+06
RZ  =  0.11800E+01
```

$\beta_2 = 0.2$

ONE-THIRD-OCTANE BAND EXCESS ATTENUATION, DB.

| FREQ HZ | RANGE DISTANCES - FEET. 250 | 500. | 1000. | 2000. | 4000. |
|---|---|---|---|---|---|
| 10.00 | -2.25 | 2.77 | 8.29 | 14.06 | 19.95 |
| 12.59 | -0.81 | 4.25 | 9.79 | 15.56 | 21.46 |
| 15.85 | 1.00 | 6.10 | 11.67 | 17.46 | 23.36 |
| 19.95 | 2.60 | 7.74 | 13.32 | 19.13 | 25.03 |
| 25.12 | 3.33 | 9.10 | 14.70 | 20.51 | 26.42 |
| 31.62 | 4.36 | 10.16 | 15.76 | 21.57 | 27.49 |
| 39.81 | 5.77 | 10.94 | 16.54 | 22.35 | 28.27 |
| 50.12 | 6.37 | 11.51 | 17.09 | 22.89 | 28.80 |
| 63.10 | 6.84 | 11.92 | 17.48 | 23.27 | 29.17 |
| 79.43 | 7.24 | 12.25 | 17.76 | 23.54 | 29.43 |
| 100.00 | 7.62 | 12.53 | 18.00 | 23.75 | 29.64 |
| 125.89 | 7.99 | 12.80 | 18.22 | 23.95 | 29.82 |
| 158.49 | 8.35 | 13.07 | 18.44 | 24.13 | 29.99 |
| 199.53 | 8.64 | 13.32 | 18.64 | 24.31 | 30.18 |
| 251.19 | 8.73 | 13.45 | 18.76 | 24.41 | 30.30 |
| 316.23 | 8.43 | 13.33 | 18.69 | 24.36 | 30.25 |
| 398.11 | 7.60 | 12.77 | 18.25 | 24.02 | 29.89 |
| 501.19 | 6.24 | 11.66 | 17.30 | 23.16 | 29.07 |
| 630.95 | 4.55 | 10.03 | 15.81 | 21.72 | 27.67 |
| 794.33 | 2.72 | 8.10 | 13.92 | 19.86 | 26.25 |
| 1000.00 | 0.92 | 6.03 | 11.81 | 17.75 | 24.03 |
| 1258.92 | -0.75 | 3.96 | 9.62 | 15.53 | 21.68 |
| 1584.89 | -2.21 | 1.98 | 7.45 | 13.38 | 19.35 |
| 1995.26 | -3.36 | 0.12 | 5.34 | 11.15 | 17.08 |
| 2511.88 | -4.05 | -1.57 | 3.32 | 9.00 | 14.87 |
| 3162.27 | -4.02 | -3.02 | 1.42 | 6.91 | 13.18 |
| 3981.05 | -2.06 | -4.14 | -0.35 | 4.93 | 10.98 |
| 5011.86 | 1.32 | -4.77 | -1.95 | 3.04 | 8.90 |
| 6309.54 | 3.94 | -4.57 | -3.30 | 1.34 | 6.87 |
| 7943.25 | -1.98 | -2.83 | -4.29 | -0.25 | 5.06 |
| 9999.96 | -3.08 | 0.35 | -4.71 | -1.37 | 3.76 |

# APPENDIX

# COMPUTER PROGRAM DESCRIPTION

By

D. M. Lister

WYLE LABORATORIES

COMPUTER PROGRAM DESCRIPTION

| | |
|---|---|
| Program Number: | 72/002S-1 |
| Author : | D. M. Lister |
| Date : | January 28, 1972 |
| Computer : | XDS Sigma 5 |
| Source Language: | Fortran IV-H |
| Monitor System : | RBM - 1 |

## 1.0 PROGRAM TITLE

Computation of ground attenuation effects on noise spectra.

## 2.0 PURPOSE

Given a mathematical definition of source height, refraction and specific admittance coeffients, the program computes the spectral sound attenuation for five (5) horizontal distances (x) from the source. The attenuation is computed at five (5) heights for each x and the average recorded. A third-octave averaging process is performed in order to smooth the results. The user has direct control over the choice of spectral and averaged plots to be produced.

## 3.0 METHOD

The method employed is described in Reference 1.

## 4.0 COMPUTER CONFIGURATION

The required hardware: XDS Sigma 5 computer with 16K core, card reader, lineprinter and Calcomp plotter.

## 5.0 DATA INPUT

The data input is in the form of punched cards, the formats of which are described in the following table.

| Note | Card | Variable | Fortran Symbol | Description | Format | Card Columns |
|---|---|---|---|---|---|---|
| 1 | 1 | – | IP2 (1) | Plot control parameters for 1/3 octave averaged plots | I1 | 1 |
| | | | IP2 (2) | IP2 (I) controls plot for range I | I1 | 2 |
| | | | IP2 (3) | If IP2 (I) = 0 then no plot for range I | I1 | 3 |
| | | | IP2 (4) | If IP2 (I) = 1 then plot on new axes | I1 | 4 |
| | | | IP2 (5) | If IP2 (I) = 2 then plot on existing axes | I1 | 5 |
| 5 | 2 | Sy | SYIN | The source height | F5.0 | 1-5 |
| | | | YSC | Scale factor for y - coordinates | F5.0 | 6-10 |
| | | | YRE | The receiver height | F5.0 | 11-15 |
| 2 | | $\beta_2$ | B2 | The specific admittance coefficient at the ground | 2F5.0 | 16-25 |
| 2 | | | HH | Ground cover layer thickness | 2F5.0 | 26-35 |
| 4 | | k | SK | Structure factor that introduces into equations nature of intersticies in skeleton | F5.0 | 36-40 |
| | | Y | Y | Porosity | F5.0 | 41-45 |
| 3 | | $R_1$ | RI | Alternating flow resistance | F5.0 | 46-50 |
| | | $\rho_m$ | RM | Density of acoustical material | F5.0 | 51-55 |
| 3 | | Q | Q | Volume coefficient of elasticity of acoustical material | F5.0 | 56-60 |

NOTES:

1. After processing each set of data the program returns to read another set of data - if an END-OF-FILE is read then the program will terminate.

2. These variables are complex numbers, hence the real part followed by the imaginary part must be supplied.

3. These variables are multiplied by 1000 by the program, thus adjust accordingly before input.

4. See Reference 2 for full description of this and following parameters.

5. All the dimensional units follow the mks system.

## 6.0 LINEPRINTER OUTPUT

This consists of an annotated copy of the input data, and a table of attenuations at various range distances for the frequency range of interest.

## 7.0 CALCOMP PLOTTER OUTPUT

This consists of plots of the attenuation levels requested for a frequency range, on a log scale, from 10 Hz to 10000 Hz. The range of the attenuation levels is from -10 db to 40 db on a linear scale.

## 8.0 DATA STATEMENT OF PROGRAM

The number of frequency points per decade (ANN) is preset by a DATA statement to be 100.
The program will always compute three decades of frequency beginning at FRZ which is preset to 10 Hz.
The spectral plots for the various range distances may be obtained by altering the array IPI according to the rules specified in section 5.0 for the array IPI. Each member of the array IPI is currently set to zero.

## 9.0 REFERENCES


1. Pao, S. P., and Evans, L. B., "Sound Attenuation Over Simulated Ground Cover," Journal of the Acoustical Society of America, Vol. 49, pp 1069-1075, 1971.

2. Beranek, L. L., "Noise Reduction," McGraw Hill Book Company, Inc., pp 257-260 1960.

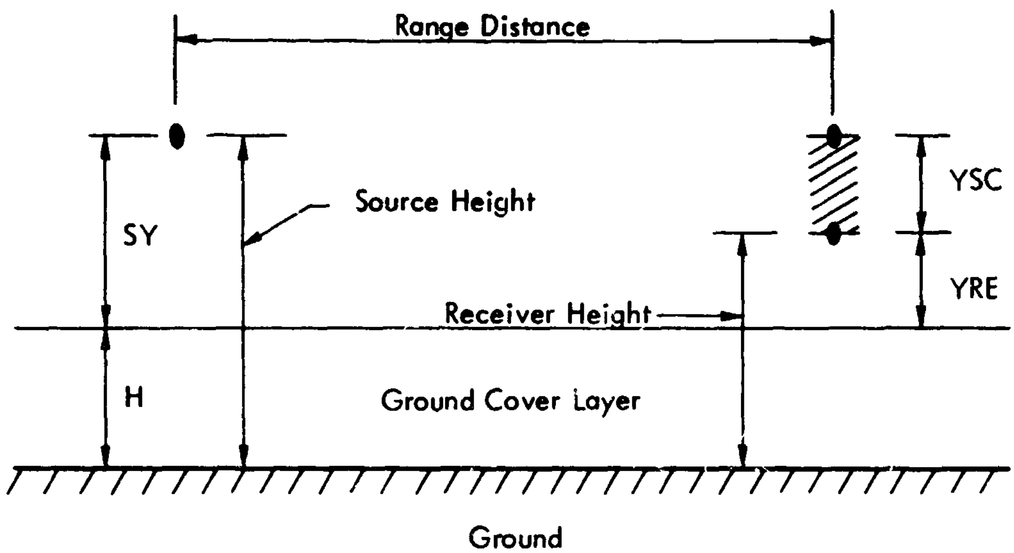


Figure A-1. Geometrical Configuration

```
C
C ***
C
      COMPLEX SGD,BD1
      COMPLEX V1A(46),V2A(46),AN1(46),AN2(46)
      COMPLEX GZ,G1,B1,B2,SIG,SI2,V1,VD1,VDD1,V2,VD2,VDD2,G72,G12,TEMP,R
     1Z,R1,RZ2,R12,R2,R22,H,FNC,EN1,EN2,TW,TEMP2,AK,HH,ZZER
C
      COMMON/LIMITS/CZERO
C
      COMMON/SVV/GZ,B1,B2,V1,VD1,VDD1,V2,VD2,VDD2,G1,H,SIG,TWOPI,XZ(5),Y
     1Z(5),IPI(5),ANN,FKZ,IP2(5),HH,ZZER
C
      COMMON SGD(301),BD1(301)
      COMMON FRQ(301),OOP(301),X(31),Y(31,5),DB(5),PARM(7),W,DUM(12)
C
      DIMENSION AKD(1)
      DIMENSION HD(2),RZD(2),R1D(2),TWD(2),GZD(2),AK(2),HHD(2),B1D(2),SI
     1GD(2),ZZERD(2)
C
      EQUIVALENCE (AKD,FRQ)
      EQUIVALENCE (HD,H,HR),(HD(2),HI),(RZD,RZ,R),(RZD(2),RI),(FN,FNC),(
     1R1D,RR1,R1),(RRI,R1D(2)),(RZ2,RR),(RP12,R12),(TW,TWD,TWR),(TWD(2),
     2TWI),(GZD,GZ,GZR),(GZD(2),GZI),(AK,AKR),(AK(2),AKI)
      EQUIVALENCE (HHD,HH,HHR),(HHD(2),HHI),(B1D,B1),(SIGD,SIG)
      EQUIVALENCE (ZZERO,ZZER,ZZERD),(ZZERI,ZZERD(2))
C
      DATA TWOPI/6.2831853/
      DATA ANN,FRZ,CZERO,ZZERO,ZZERI/100.0,10.0,345.31,410.0,0.0/
      DATA XZ/1219.2,609.6,304.8,152.4,76.2/
      DATA YZ/0.0,0.25,0.5,0.75,1.0/
      DATA IPI /0,0,0,0,0/
C
      CALL PLOT (0.0,-12.0,25)
      CALL PLOT (0.0,1.5,25)
 2    FNC=(0.0,0.0)
      RZ2=FNC
      R12=FNC
      RRI=0.0
      RI=0.0
      GZI=0.0
      AKI=0.0
      H=FNC
C
C***
C
      READ (105,3,END=999) (IP2(I),I=1,5)
 3    FORMAT (5I1)
      READ (105,4) SYIN,YSC,YRE,B2,HH,(PARM(I),I=1,5)
 4    FORMAT (16F5.0)
      PARM(3)=PARM(3)*1000.0
      PARM(5)=PARM(5)*1000.0
      PARM(6)=100000.0
      PARM(7)=1.18
      WRITE(108,100) SYIN,YSC,YRE,HHR,B2
      WRITE(108,110) (PARM(I),I=1,7)
      DO 20 J=1,5
      AN=0.0
      K=0
```

```
      FRR=FR7
5     K=K+1
      FRQ(K)=FRR
      W=TWOPI*FRR
      AKR=W/CZERO
      IF (J-1) 6,7,8
6     STOP 6
7     CALL IMP(HD,SIGD)
      B1=ZZER/H
      BD1(K)=B1
      SGD(K)=SIG
      GO TO 9
8     B1=BD1(K)
      SIG=SGD(K)
9     XX=XZ(J)*AKR
      HR=HHR*AKR
      HI=HHI*AKR
      X2=XX*XX
      SY=SYIN*AKR
      SY=SY+HR
      Z=HR*HR+HI*HI
      PSG=0.0
      DO 18 I=1,5
      YY=YZ(I)*YSC*AKR+HR+YRE*AKR
      T1=YY-SY
      T2=T1*T1
      RR=T2+X2
      R=SQRT(RR)
      T1=YY+SY-HR*2.0
      T2=T1*T1
      RR12=T2+X2
      RR1=SQRT(RR12)
      GZR=T1/RR1
      GZR2=GZR*GZR
      FN=0.5*(1.0-GZR2)
      CALL CV1V2
      EN1=FNC*VDD1-GZ*VD1
      EN2=FNC*VDD2-GZ*VD2
      R2=R1+(2.0,0.0)*H*(G1*SIG-GZ)
      TEMP=(0.0,1.0)*(R2-R7)
      TEMP=CEXP(TEMP)
      TEMP=TEMP*RZ/R1
      TEMP2=R1/ H
      TW=TEMP*(V2-(0.0,1.0)*EN2/TEMP2)
      TEMP=(0.0,1.0)*((R12-RZ2)/(R1+RZ))
      TEMP=CEXP(TEMP)
      TEMP=TEMP*RZ/R1
      TEMP2=EN1/R1
      TEMP2=TEMP2*(0.0,1.0)
      TEMP2=V1-TEMP2
      TEMP=TEMP*TEMP2
      TW=TW+(1.0,0.0)
      TW=TW+TEMP
      ABC=TWR*TWR+TWI*TWI
18    PSG=PSG+ABC
      BBP(K)=5.0/PSG
      AN=AN+1.0
      FRR=FR7*10.0**(AN/ANN)
      IF (K.LT.301) GO TO 5
```

```
      CALL PLOTIT (FRQ,OOP,301,IPI(J))
      CALL TOV(J)
20    CONTINUE
      X(1)=AKD(1)
      DO 22 I=2,30
      K=(I-1)*10+1
22    X(I)=AKD(K)
      X(31)=AKD(301)
      DO 30 J=1,5
      CALL PLOTIT (X,Y(1,J),31,IP2(J))
30    CONTINUE
      WRITE (108,31)
31    FORMAT (///16X,45HONE-THIRD-OCTANE BAND EXCESS ATTENUATION, DB./
     111X,55(1H-)//11X,4HFREQ,18X,23HRANGE DISTANCES - FEET./12X,2HHZ,9X
     2,3H250,7X,5H 500.,5X,5H1000.,5X,5H2000.,5X,5H4000./11X,4(1H-),7X,4
     35(1H-)/)
      DO 40 I=1,31
      DO 32 J=1,5
32    DB(J)=10.0*ALOG10(Y(I,J))
      WRITE (108,34) X(I),DB(5),DB(4),DB(3),DB(2),DB(1)
34    FORMAT (5X,F10.2,5X,5(F8.2,2X))
40    CONTINUE
      WRITE (108,50)
50    FORMAT (1H1)
      GO TO 2
100   FORMAT (10X,5HSY  = ,E12.5/
     1           10X,5HYSC= ,E12.5/
     A           10X,5HYRE= ,E12.5/
     B           10X,5HH   = ,E12.5/
     2           10X,5HB2  = ,E12.5,3H , ,E12.5)
110   FORMAT (10X,5HSK  = ,E12.5/
     1           10X,5HY   = ,E12.5/
     2           10X,5HR1  = ,E12.5/
     3           10X,5HRM  = ,E12.5/
     4           10X,5HG   = ,E12.5/
     5           10X,5HCK  = ,E12.5/
     6           10X,5HRZ  = ,E12.5)
999   STOP 999
      END

      SUBROUTINE TOV(J)
      COMMON SPARE(1204)
      COMMON X1(301),Y1(301),X2(31),Y2(31,5)
      SUM=1.0/Y1(1)+1.0/Y1(2)+1.0/Y1(3)+1.0/Y1(4)+1.0/Y1(5)+1.0/Y1(6)
      Y2(1,J)=6.0/SUM
      SUM=1.0/Y1(300)+1.0/Y1(299)+1./Y1(298)+1./Y1(297)+1./Y1(296)+1.0/Y
     11(301)
      Y2(31,J)=6.0/SUM
      DO 10 I=2,30
      SUM=0.0
      KE=I*10-5
      KS=KE-8
      DO 6 K=KS,KE
6     SUM=SUM+1.0/Y1(K)
      SUM=SUM+2.0/(Y1(KS-1)+Y1(KE+1))
10    Y2(I,J)=10.0/SUM
      RETURN
      END
```

```
      SUBRØUTINE CV1V2
      CØMPLEX TEMPA,TEMPB,H
      CØMPLEX GZ,G1,B1,B2,SIG,SI2,V1,VD1,VDD1,V2,VD2,VDD2,GZ2,G12,TEMP
      CØMMØN/SVV/GZ,B1,B2,V1,VD1,VDD1,V2,VD2,VDD2,G1,H,SIG,TWØPI
      DIMENSIØN SD(2)
      EQUIVALENCE (SD,SIG,SIR),(SD(2),SII),(GZR,GZ)
C ***
      XS=ABS(SII)
      IF (XS-1.0E-9) 100,100,108
  100 XS=ABS(SIR)
      XS=ABS(XS-1.0)
      IF (XS-1.0E-9) 102,102,108
  102 VD1=(0.0,0.0)
      VDD1=VD1
      V1=((1.0,0.0)-B1)/((1.0,0.0)+B1)
      V2=(4.0,0.0)*B1*(GZ-B2)/(GZ+B2)/((1.0,0.0)+B1)/((1.0,0.0)+B1)
      XS=ABS(GZR)
      IF(XS-2.0E-1) 104,104,106
  104 VD2=VD1
      VDD2=VD2
      RETURN
  106 VD2=(8.0,0.0)*B1*B2/((1.0,0.0)+B1)/((1.0,0.0)+B1)/(GZ+B2)/(GZ+B2)
      VDD2=VD2*(-2.0,0.0)/(GZ+B2)
      G1=GZ
      GØ TØ 200
  108 CØNTINUE
      SI2=SIG*SIG
      GZ2=GZ*GZ
      G1=SI2+GZ2-(1.0,0.0)
      G1=CSQRT(G1)
      G1=G1/SIG
      G12=G1*G1
      V1=(GZ-B1*G1)/(GZ+B1*G1)
      VD1=(2.0,0.0)*B1*(G12*SI2-GZ2)/SI2/G1/(GZ+B1*G1)/(GZ+B1*G1)
      VD2=-VD1*(GZ2+(2.0,0.0)*G12*SI2+(3.0,0.0)*GZ*G1*B1)/(SI2*G12*(GZ+B
     11*G1))
      VDD1=VD2
      TEMP=(GZ+B1*G1)
      TEMP=TEMP*TEMP
      V2=(G1-B2)*(4.0,0.0)*B1*GZ*G1/(TEMP*(G1+B2))
      XS=ABS(GZR)
      IF (XS-1.0E-9) 160,160,170
  160 VD2=(0.0,0.0)
      VDD2=VD2
      RETURN
  170 VD2=(8.0,0.0)*B1*B2*GZ2/(SI2*TEMP*(G1+B2)*(G1+B2))
      VD2=VD2+V2*V1*((1.0,0.0)-SI2)/SI2/G12/GZ
      VDD2=((1.0,0.0)-SI2)/SI2/G12/GZ*((V1*VD2+VD1*V2)-V1*V2*(SI2*G12+GZ
     12*(2.0,0.0))/SI2/GZ/G12)
      TEMP=GZ/((GZ+B1*G1)*SIG*(G1+B2))
      TEMP=TEMP*TEMP
      VDD2=VDD2+(16.0,0.0)*B1*B2*TEMP*((1.0,0.0)/GZ-(SI2*G1+B1*GZ)/SI2/G
     11/(GZ+B1*G1)-GZ/SI2/G1/(G1+B2))
  200 TEMPA=GZ*(0.0,2.0)/SIG/G1
      TEMPB=TEMPA*TEMPA*H+(0.0,2.0)*(SI2-(1.0,0.0))/G12/G1/SI2/SIG
      VDD2=VDD2/H
      VD2=VD2/H
      VDD2=VDD2+(2.0,0.0)*TEMPA*VD2+TEMPB*V2
      VD2=VD2+V2*TEMPA
      RETURN
      END
```

```
      SUBROUTINE PLOTIT (X,Y,N,IP)
      DIMENSION X(1),Y(1)
      COMMON/PLUT/XST,XAXIS,XDECADE,YAXIS,YDECADE,IQ,YMIN
      COMMON/AXIS/TT(8)
      DATA TT/0.0458,0.0969,0.1549,0.2218,0.301,0.3979,0.5229,0.699/
      DATA XST,XDECADE,YDECADE,IQ/3.0,2.0,1.5,5/
      DATA YAXIS,YMIN/7.5,-10.0/
      YS=YDECADE/10.0
      IF (IP-1) 230,10,170
10    IF (ABS(X(1)-1.0)-0.00001) 20,20,30
20    XSCALE=1.0
      GO TO 60
30    XM=ALOG10(X(1))
      IF (X(1)-1.0) 40,20,50
40    I=IFIX(XM)-1
      XSCALE=1.0/10.0**I
      GO TO 60
50    I=IFIX(XM+0.5)
      XSCALE=1.0/10.0**I
60    CALL PLOT (XST,0.0,25)
      I=IFIX(ALOG10(X(N)*XSCALE)+1.0)
      XAXIS=FLOAT(I)*XDECADE
      XST=XAXIS+3.0
      CALL PLOT (XAXIS,0.0,2)
      CALL PLOT (XAXIS,YAXIS,2)
      CALL PLOT (0.0,YAXIS,2)
      CALL PLOT (0.0,0.0,2)
      XX=XDECADE
      DO 80 K=1,I
      DO 70 J=1,8
      XD=XX-TT(9-J)*XDECADE
      CALL PLOT (XD,0.0625,1)
70    CALL PLOT (XD,0.0,2)
      CALL PLOT (XX,0.125,1)
      CALL PLOT (XX,0.0,2)
80    XX=XX+XDECADE
      XX=XAXIS
      YY=0.0
      DO 110 K=1,IQ
      YD=YY
      DO  90 J=1,4
      YD=YD+YS
      CALL PLOT (XX,YD,1)
90    CALL PLOT (XX-0.050,YD,2)
      YD=YD+YS
      CALL PLOT (XX,YD,1)
      CALL PLOT (XX-0.1,YD,2)
      DO 100 J=1,4
      YD=YD+YS
      CALL PLOT (XX,YD,1)
100   CALL PLOT (XX-0.050,YD,2)
      YY=YY+YDECADE
      CALL PLOT (XX,YY,1)
      CALL PLOT (XX-0.150,YY,2)
110   CONTINUE
      YY=YAXIS
      DO 130 K=1,I
      DO 120 J=1,8
```

```
      XD=XX-TT(J)*XDECADE
      CALL PLOT(XD,YY,1)
  120 CALL PLOT(XD,YY-0.0625,2)
      XX=XX-XDECADE
      CALL PLOT(XX,YY,1)
  130 CALL PLOT(XX,YY-0.125,2)
      DO 160 K=1,IG
      YD=YY
      DO 140 J=1,4
      YD=YD-YS
      CALL PLOT (0.0,YD,1)
  140 CALL PLOT (0.050,YD,2)
      YD=YD-YS
      CALL PLOT (0.0,YD,1)
      CALL PLOT (0.1,YD,2)
      DO 150 J=1,4
      YD=YD-YS
      CALL PLOT (0.0,YD,1)
  150 CALL PLOT (0.050,YD,2)
      YY=YY-YDECADE
      CALL PLOT (0.0,YY,1)
      CALL PLOT (0.150,YY,2)
  160 CONTINUE
  170 XX=ALOG10(X(1)*XSCALE)*XDECADE
      YY=10.0*ALOG10(Y(1))-YMIN
      IF (YY) 180,190,190
  180 YY=0.0
  190 YY=YY*YS
      IF (YY.GT.9.0) YY=9.0
      CALL PLOT (XX,YY,1)
      DO 220 I=2,N
      XX=ALOG10(X(I)*XSCALE)*XDECADE
      YY=10.0*ALOG10(Y(I))-YMIN
      IF (YY) 200,210,210
  200 YY=0.0
  210 YY=YY*YS
      IF (YY.GT.9.0) YY=9.0
      CALL PLOT (XX,YY,2)
  220 CONTINUE
  230 RETURN
      END
```

```
      SUBRØUTINE IMP(ACD,SIGD)
C
      CØMPLEX BC,XC,ZC
C
      CØMMØN/LIMITS/CZERØ
C
      CØMMØN SPARE(1204)
      CØMMØN FREQ(301),DUMMY(492),SK,Y,R1,RM,Q,CK,RZ,W,DUD
      CØMMØN ZCD(2),BCD(2),XCD(2)
C **
      DIMENSIØN ACD(2),SIGD(2)
C
      EQUIVALENCE (BCD,BC,BR),(BCD(2),BI),(XCD,XC,XR),(XCD(2),XI)
      EQUIVALENCE (ZCD,ZC,ZR),(ZCD(2),ZI)
C **
      IF (CK-Q*20.0) 100,100,120
  100 XR=1.0
      XI=-R1/RZ/SK/W
      XC=CSQRT(XC)
      BR=0.0
      BI=RZ*SK*Y/CK/1.4
      BI=W*SQRT(BI)
      BC=BC*XC
  110 ZR=0.0
      ZI=-CK/W/Y*1.4
      ZC=ZC*BC
      CM=W/BI
      SIGD(1)=CZERØ/CM
      SIGD(2)=BR*CZERØ/W
      GØ TØ 130
  120 TERM1=1.0+RZ*(SK-1.0)/RM
      TERM12=TERM1*TERM1
      TERM2=RM*W
      TERM22=TERM2*TERM2
      R12=R1*R1
      TERM3=TERM22*TERM12
      BØT4=1.0+R12/TERM3
      RZK=RZ*SK
      TØP=1.0+R12*(Y+RM/RZK)/TERM3
      BØT2=1.0+RZ*(SK-1.0)/RM
      RB1=RZK*TØP/BØT4
      RRB1=1.0+RZ*(SK-1.0)/RM
      RRB1=RRB1*RRB1
      BØT4=BØT4*RRB1
      RRB1=R1*(1.0-RZ*(1.0-Y)/RM)/BØT4
      XR=RB1
      XI=-RRB1/W
      XC=CSQRT(XC)
      BI=Y/CK/1.4
      BI=SQRT(BI)
      BI=BI*W
      BR=0.0
      BC=BC*XC
      GØ TØ 110
  130 CØNTINUE
      ACD(1)=ZR
      ACD(2)=ZI
      RETURN
      END
```

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13. ABSTRACT

In earlier portions of the present research program, a precise mathematical model was developed for the estimation of sound absorption over a ground cover layer. The usefulness and validity of this analysis was confirmed by results obtained through a laboratory-scaled experiment. In the present study, the above mentioned mathematical model is applied to the prediction of sound absorption over various types of ground covers composed of natural vegetations. Through an extensive review of literature in agriculture and forestry, the physical structure and relevant mechanical properties of ground cover canopies have been determined. The acoustical properties of the ground cover itself has also been estimated. Based on these results, ground absorption spectra over various assumed ground cover conditions have been calculated. The trends of the prediction have been compared with experimental results and the limitations of the present study are discussed.

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